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# United States Patent [19]

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Barton et al.

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[54] **STRUCTURE AND FABRICATION OF ELECTRON-EMITTING DEVICE HAVING FOCUS COATING CONTACTED THROUGH UNDERLYING ACCESS CONDUCTOR**

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[73] Assignee: **Candescent Technologies Corporation**, San Jose, Calif.

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[21] Appl. No.: **08/866,151**

[22] Filed: **May 30, 1997**

[51] Int. Cl.<sup>6</sup> ..... **H01J 19/38**

[52] U.S. Cl. .... **313/497**; 313/309; 313/336; 313/496; 313/355; 313/293; 313/348; 445/24; 445/50; 345/75

[58] Field of Search ..... 313/309, 310, 313/336, 351, 422, 495, 496, 497, 452, 348, 355, 293, 294; 345/74, 75; 445/24, 50

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### [57] ABSTRACT

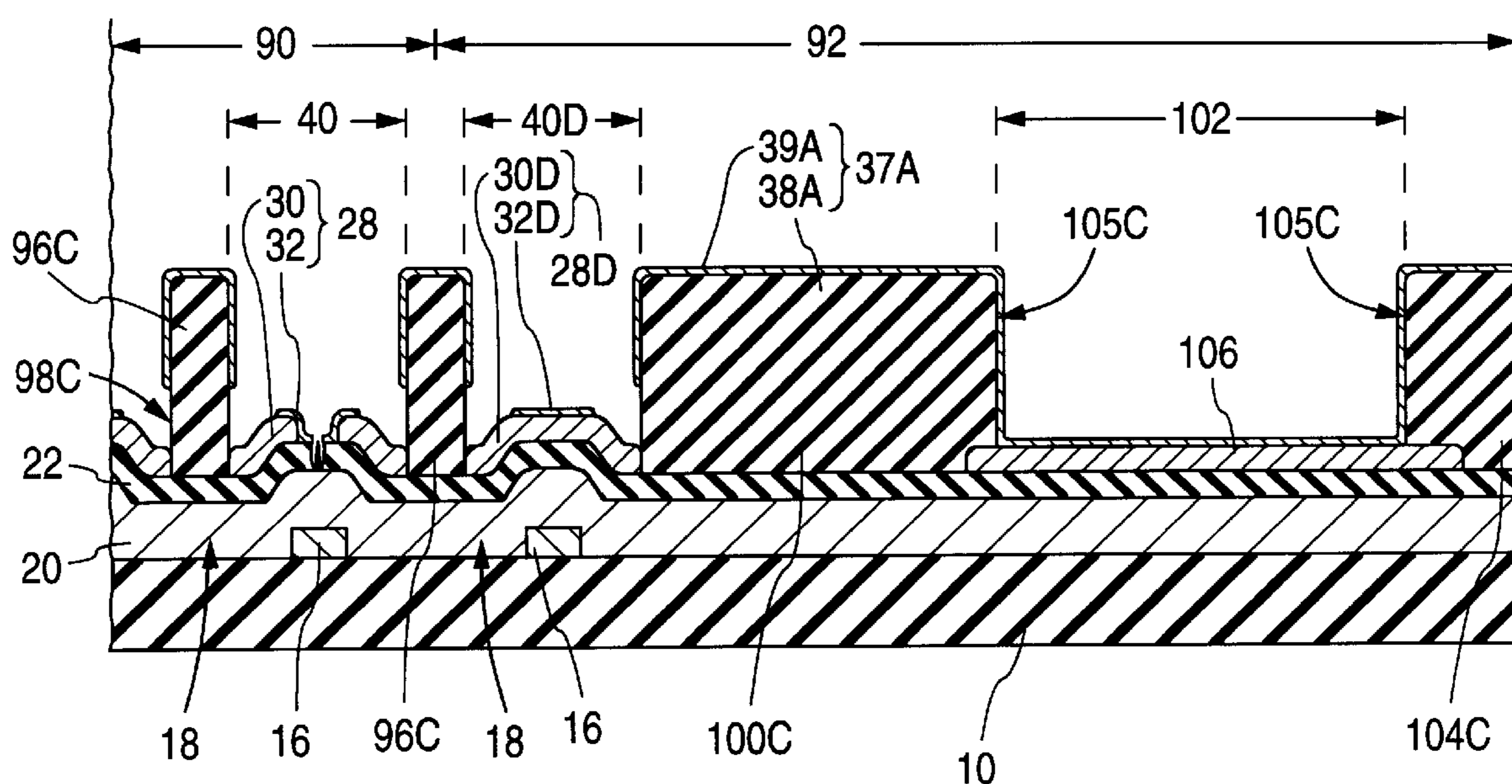
An electron-emitting device contains an electron focusing system (37 or 37A) formed with a base focusing structure (38 or 38A), a focus coating (39 or 39A), and an access conductor (106 or 116). The focus coating overlies the base focusing structure and extends into a focus opening (40). The access conductor is electrically coupled to the lower surface of the focus coating. A potential for controlling the focusing of electrons that travel through the focus opening is provided to the focus coating via the access conductor. The focus coating is typically formed by an angled deposition technique.

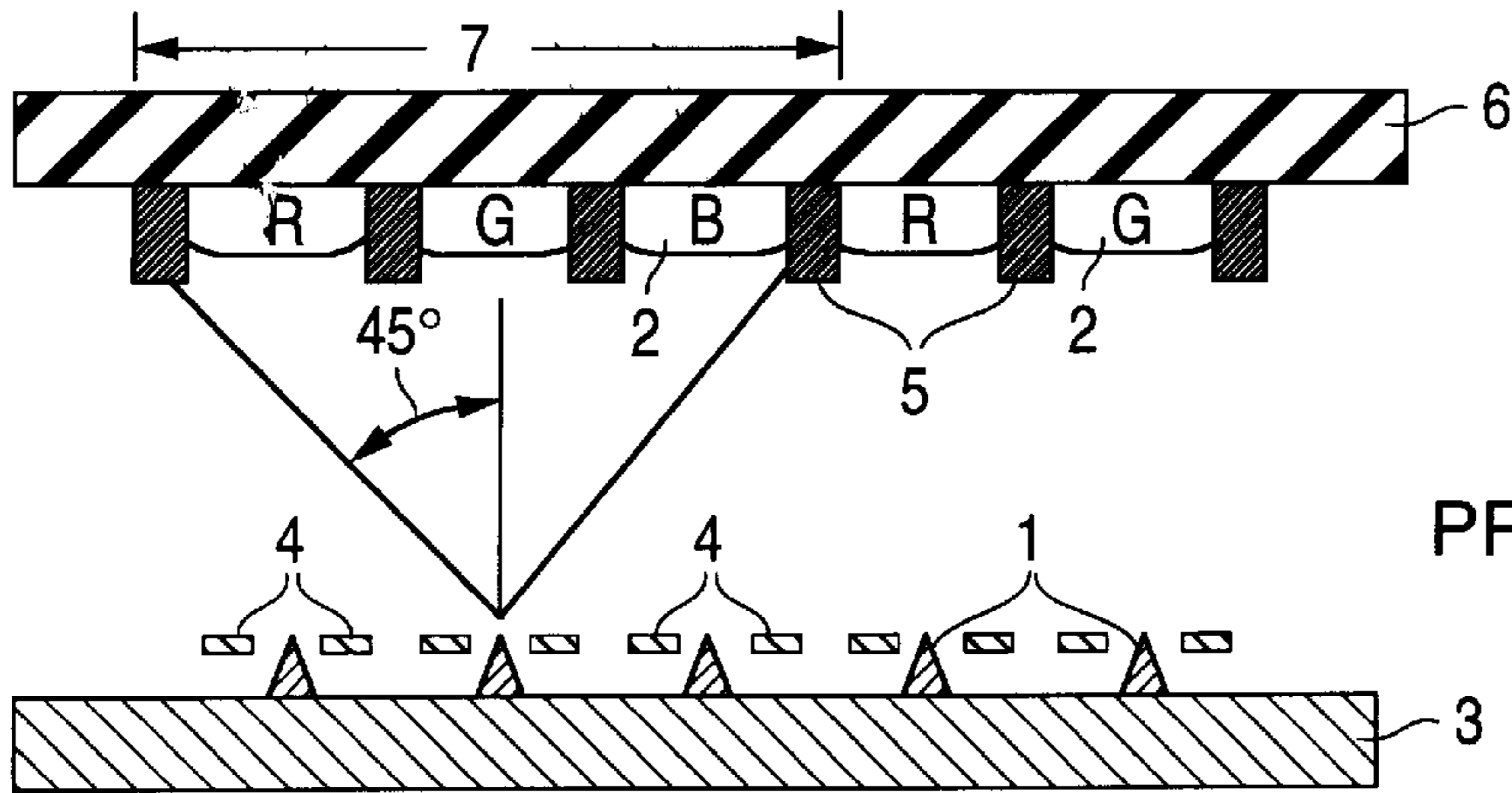
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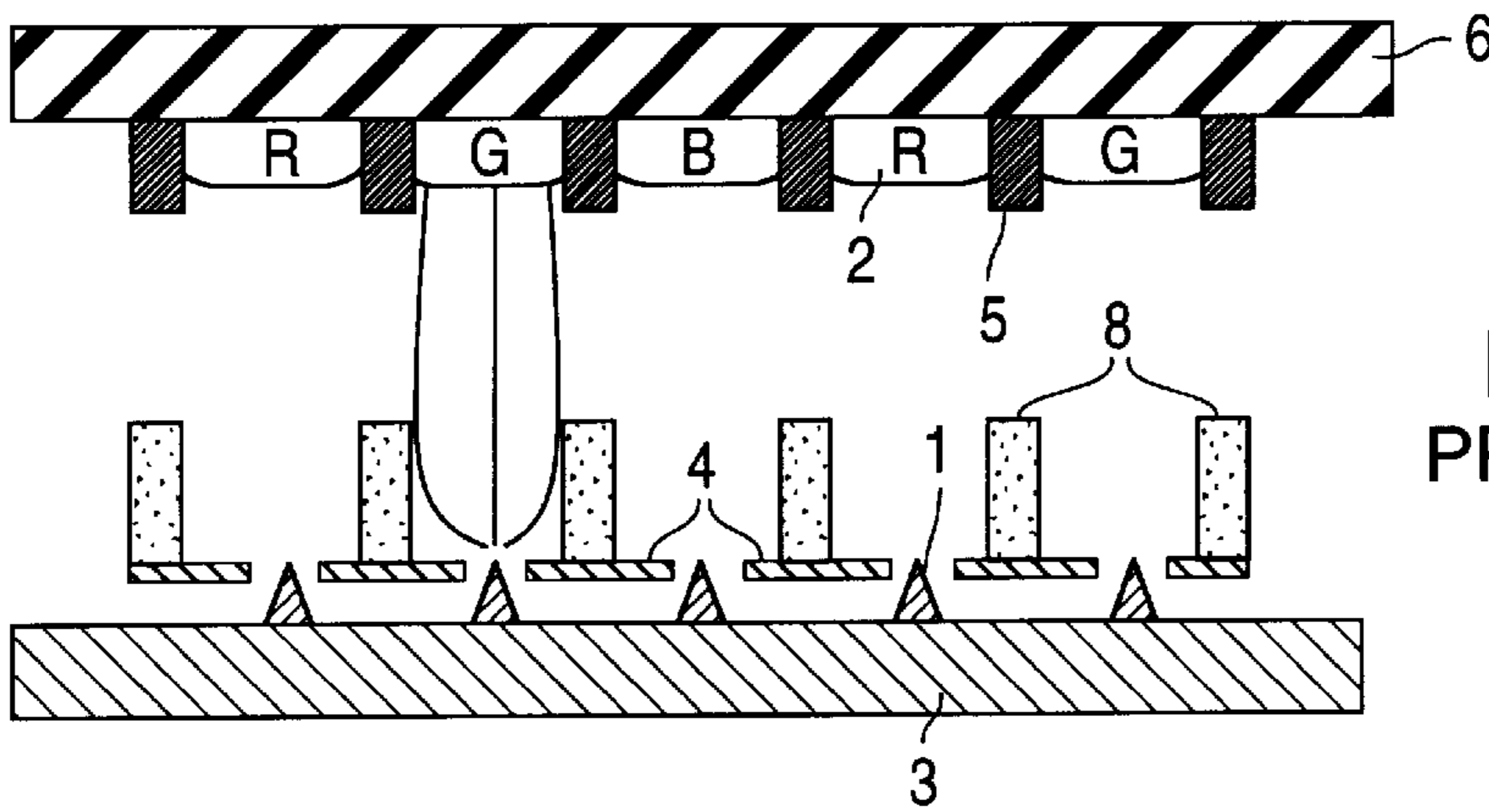
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**37 Claims, 10 Drawing Sheets**

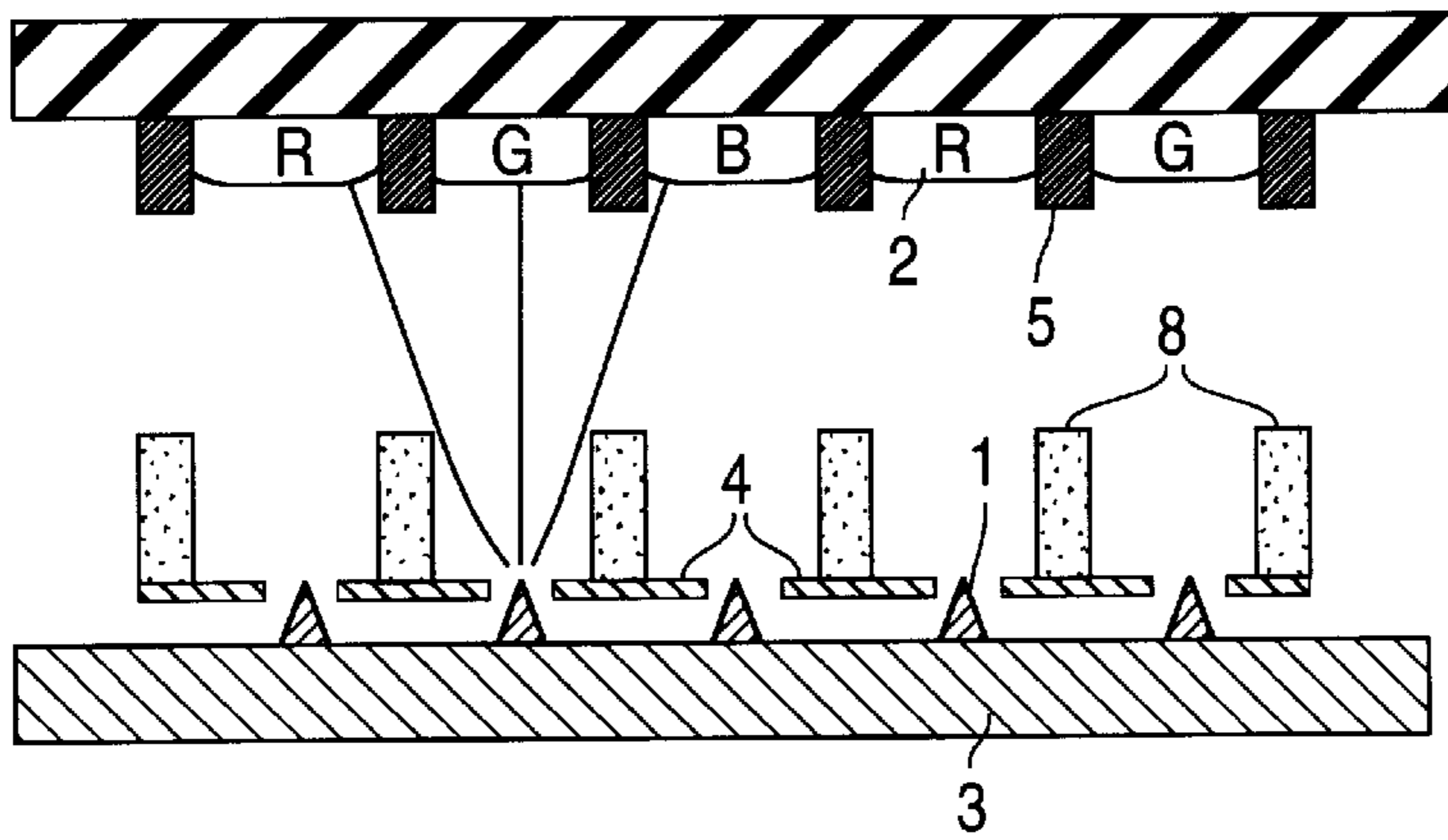




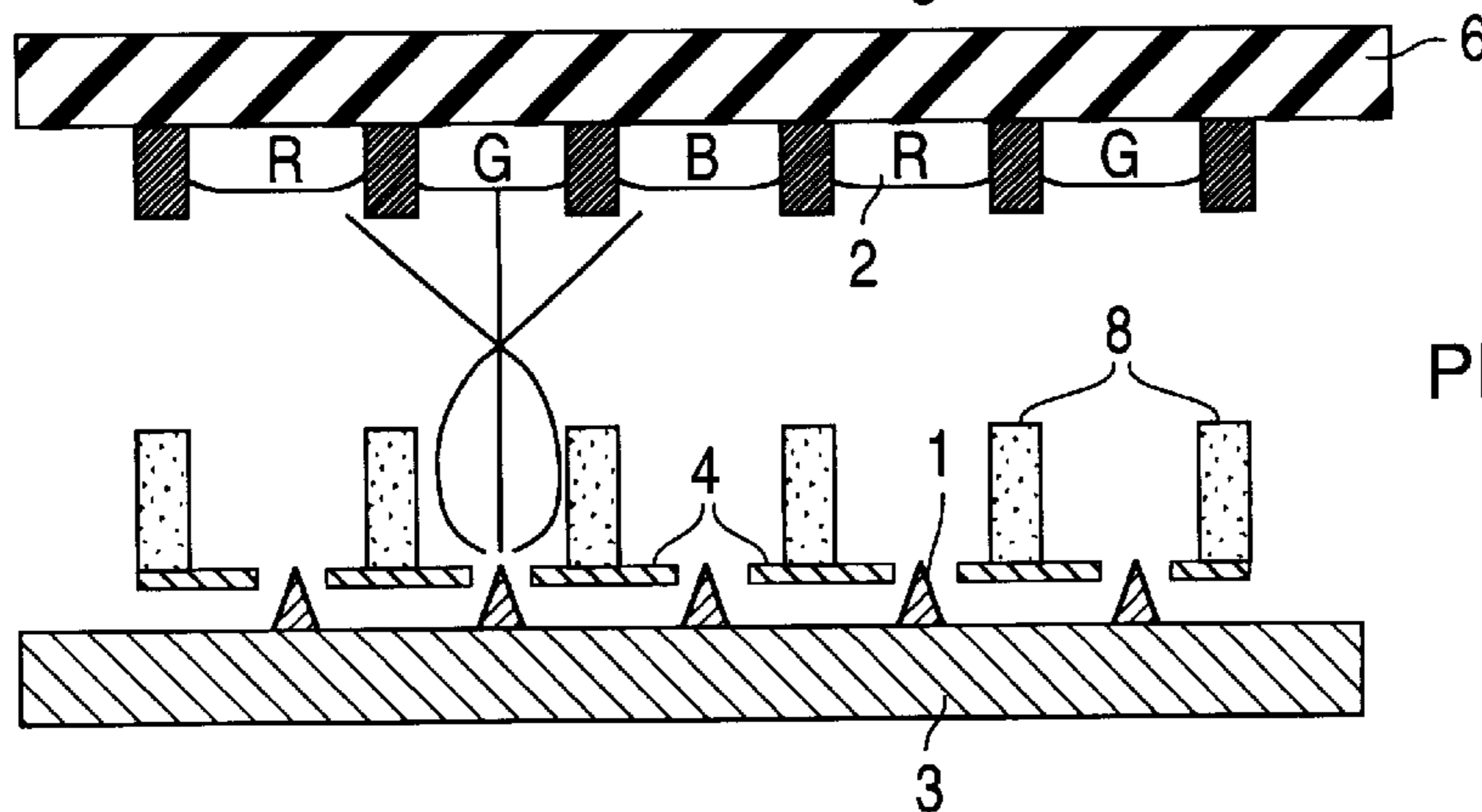
**Fig. 1**  
PRIOR ART



**Fig. 2a**  
PRIOR ART



**Fig. 2b**  
PRIOR ART



**Fig. 2c**  
PRIOR ART

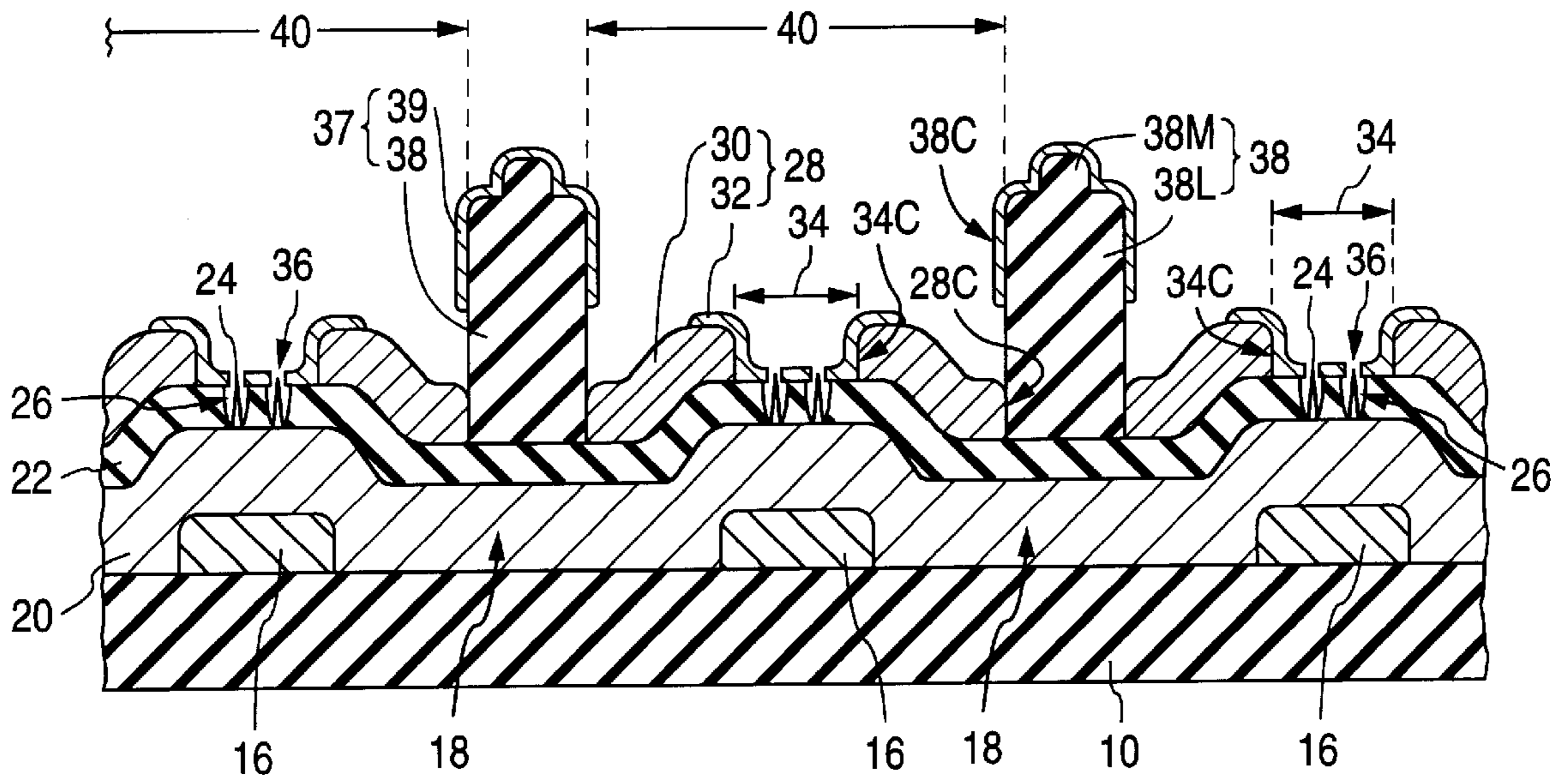


Fig. 3

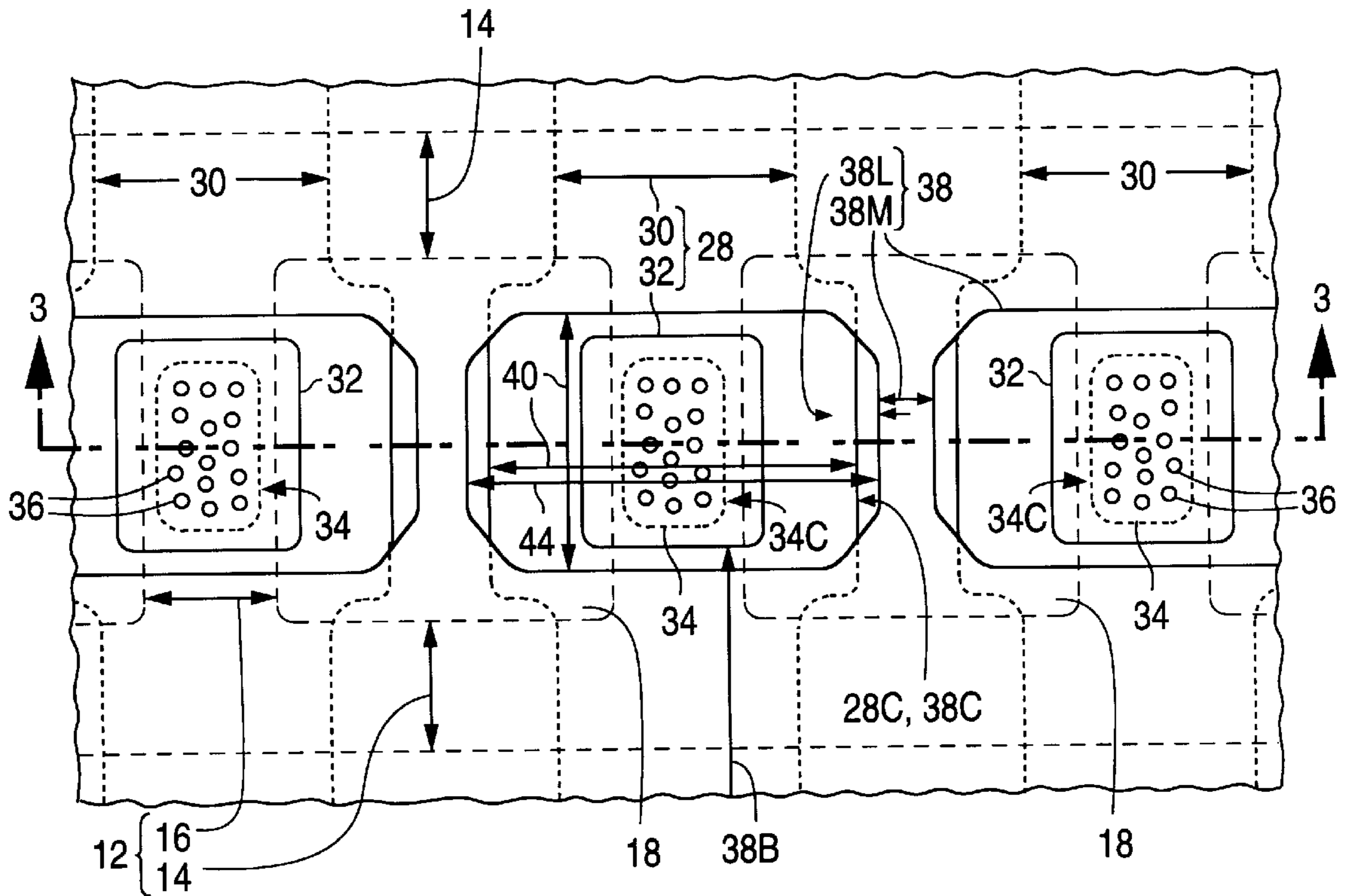


Fig. 4

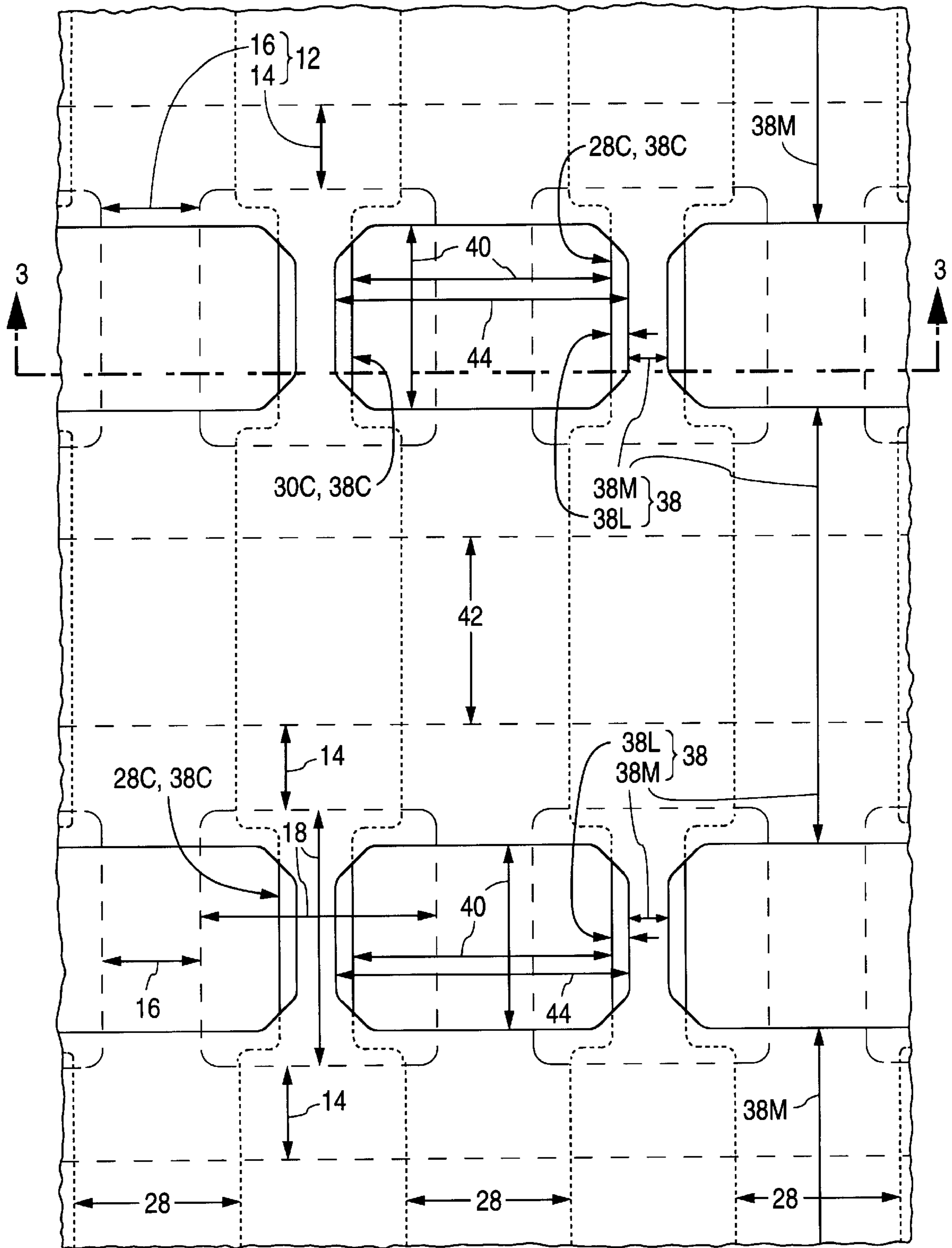


Fig. 5

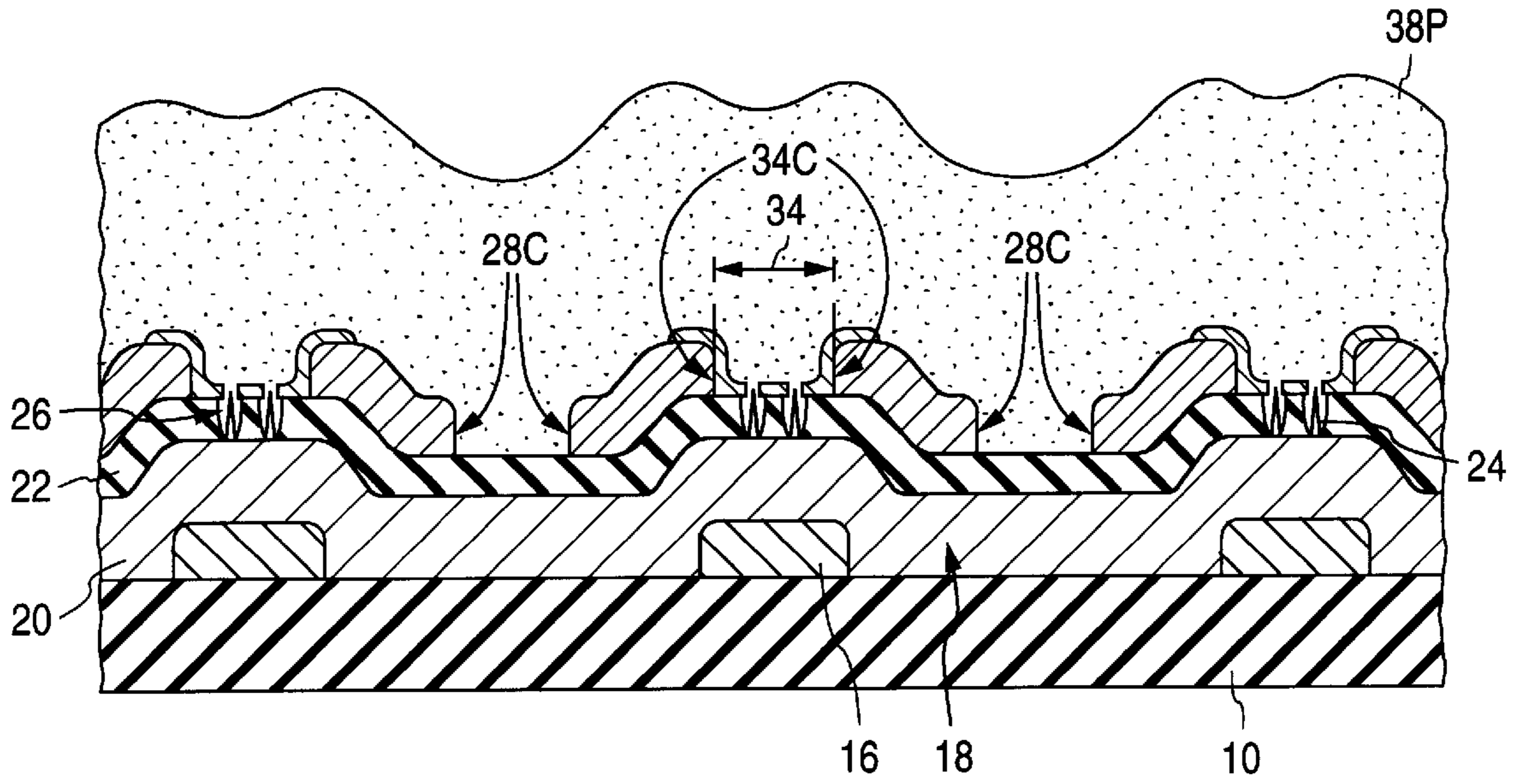


Fig. 6a

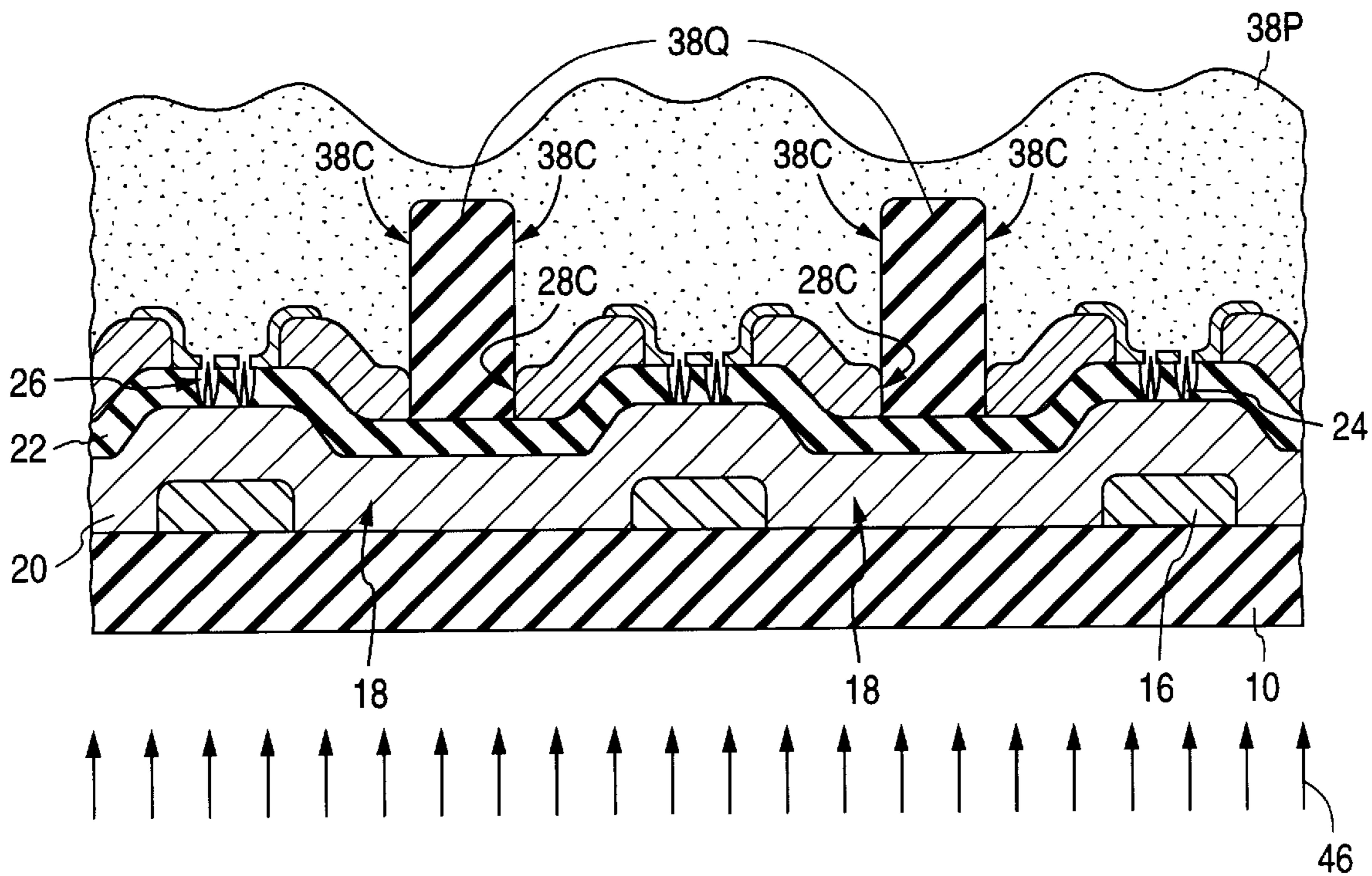


Fig. 6b

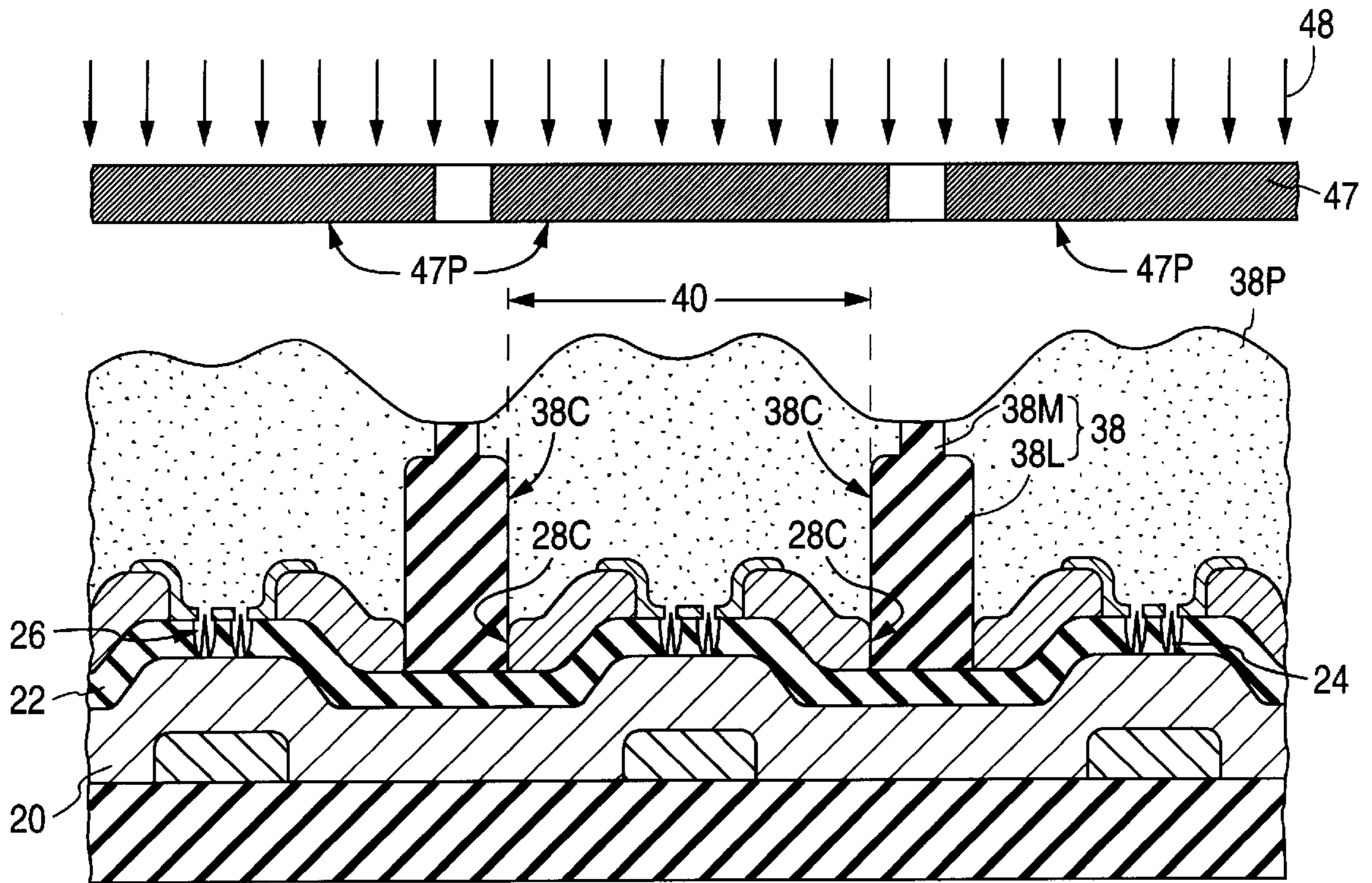


Fig. 6c

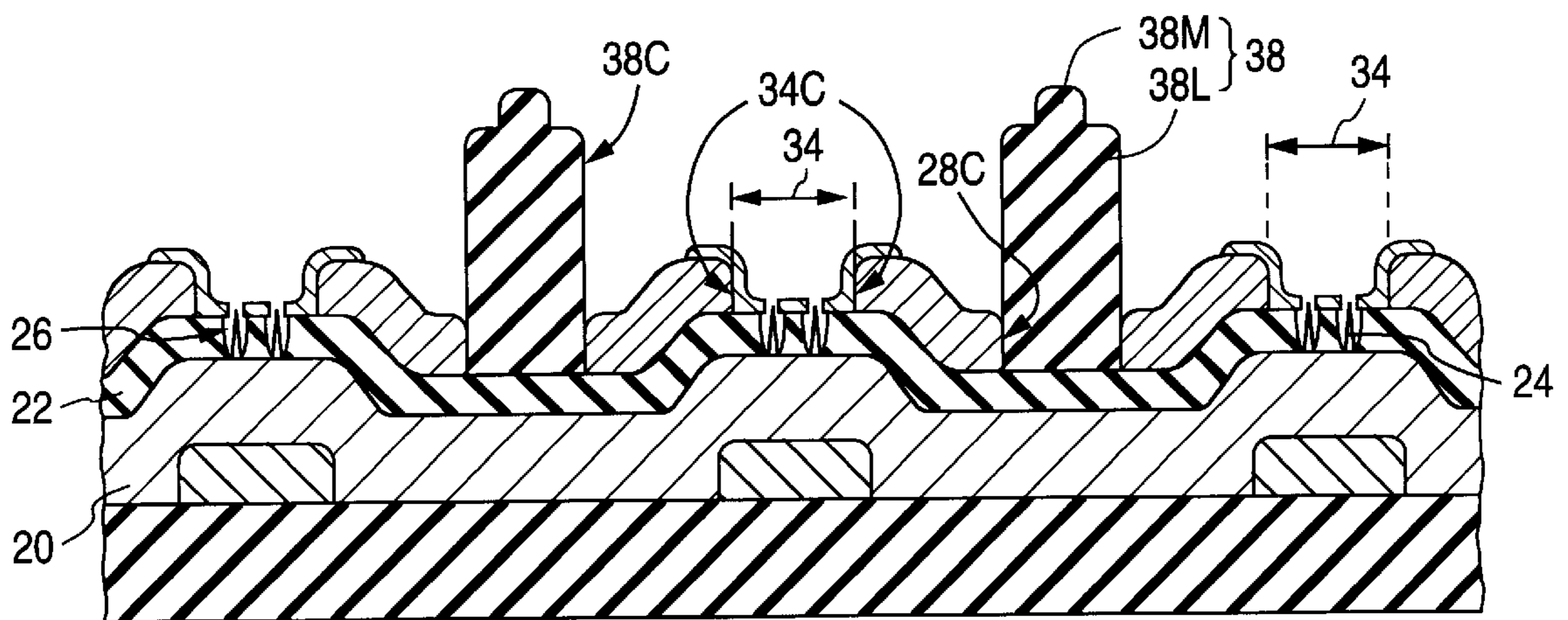


Fig. 6d

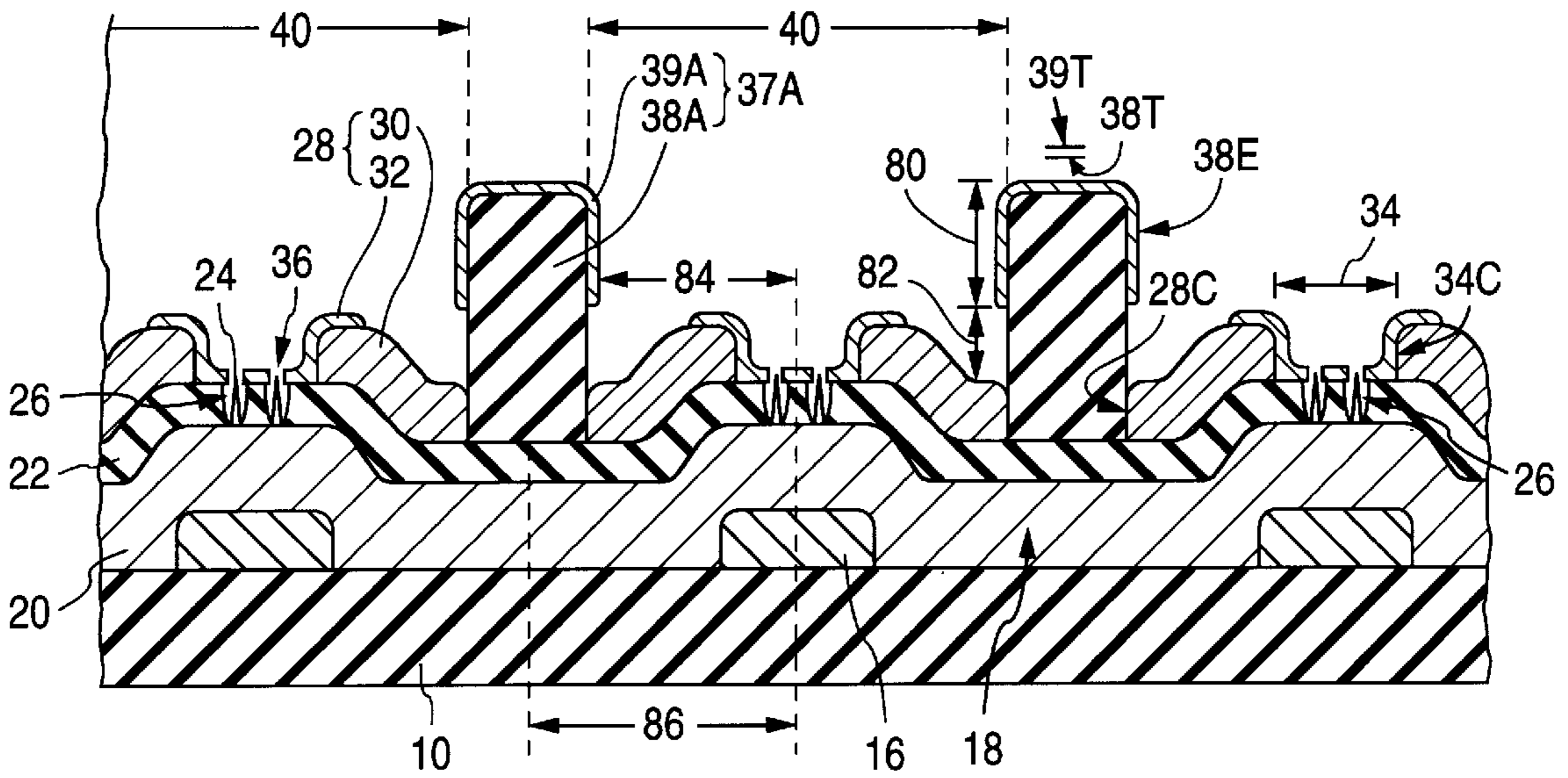


Fig. 7

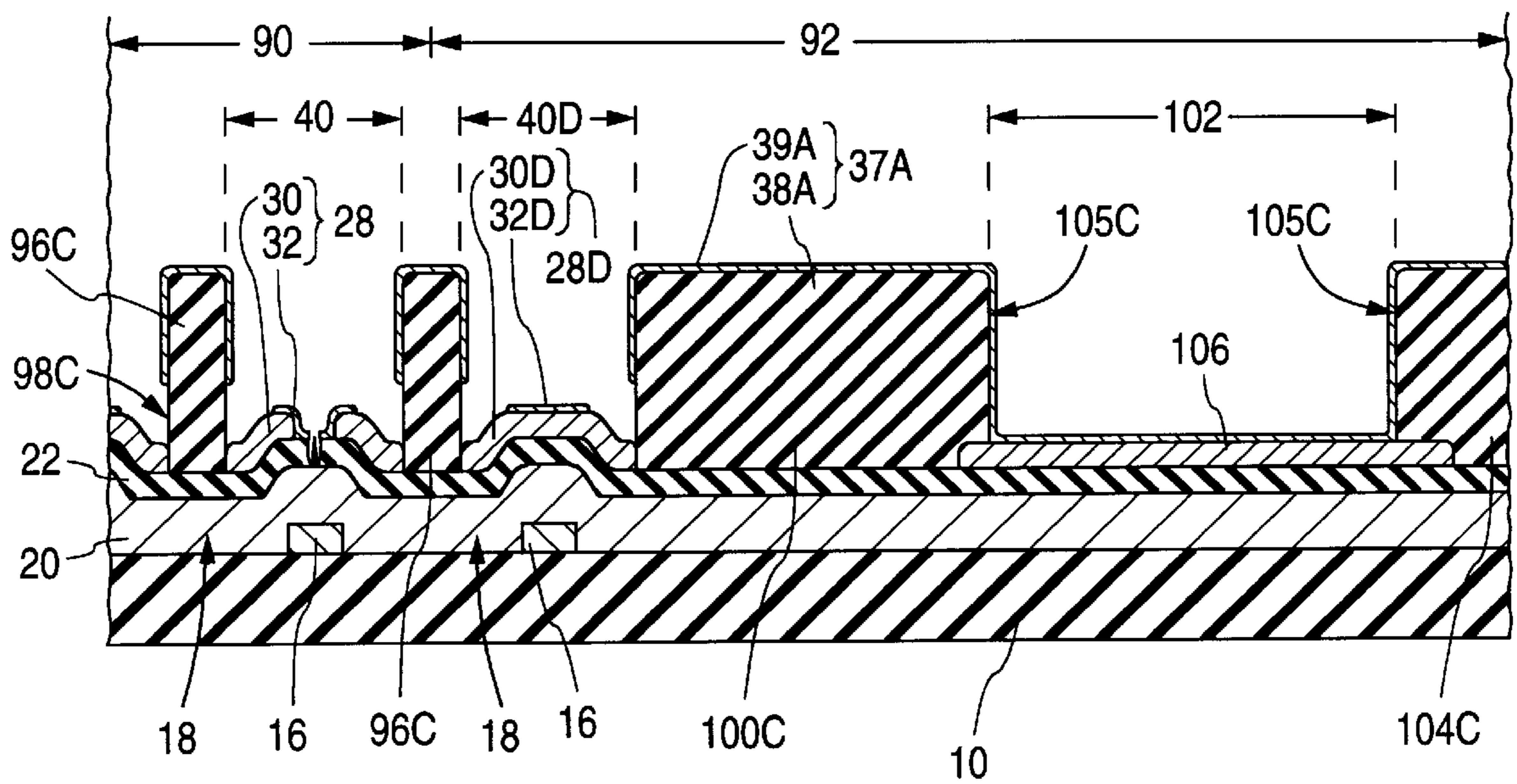
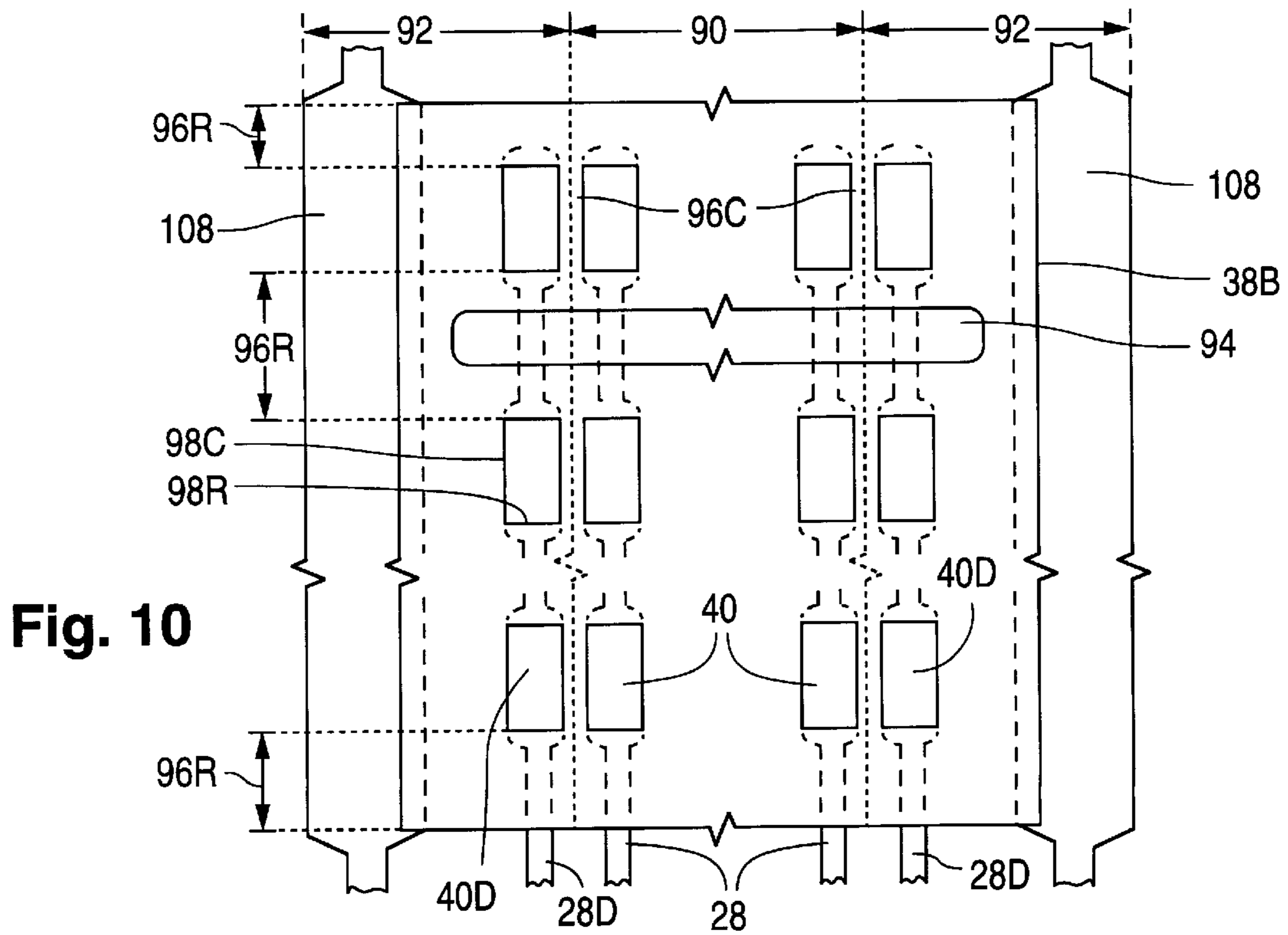
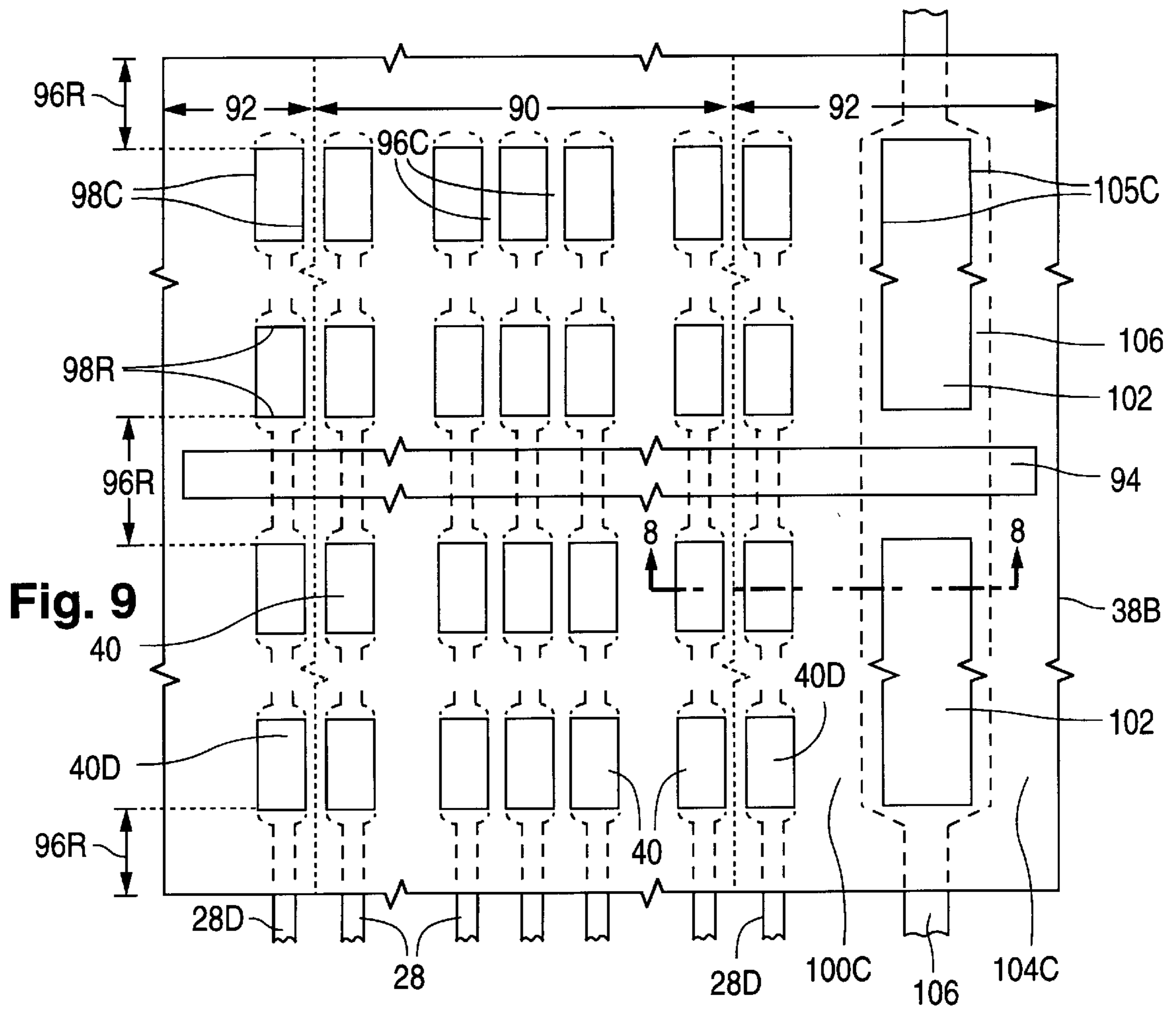


FIG. 8





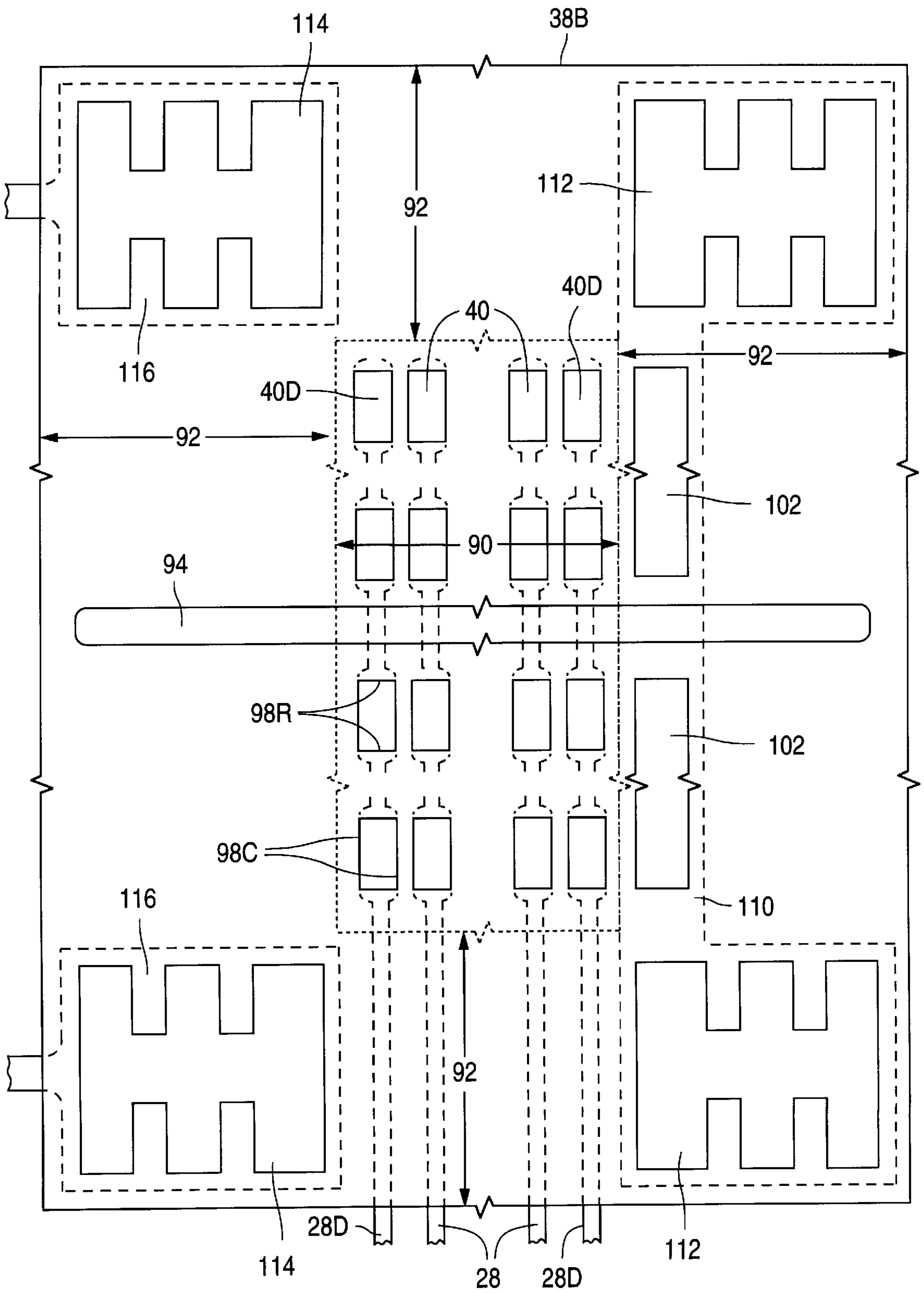


Fig. 11

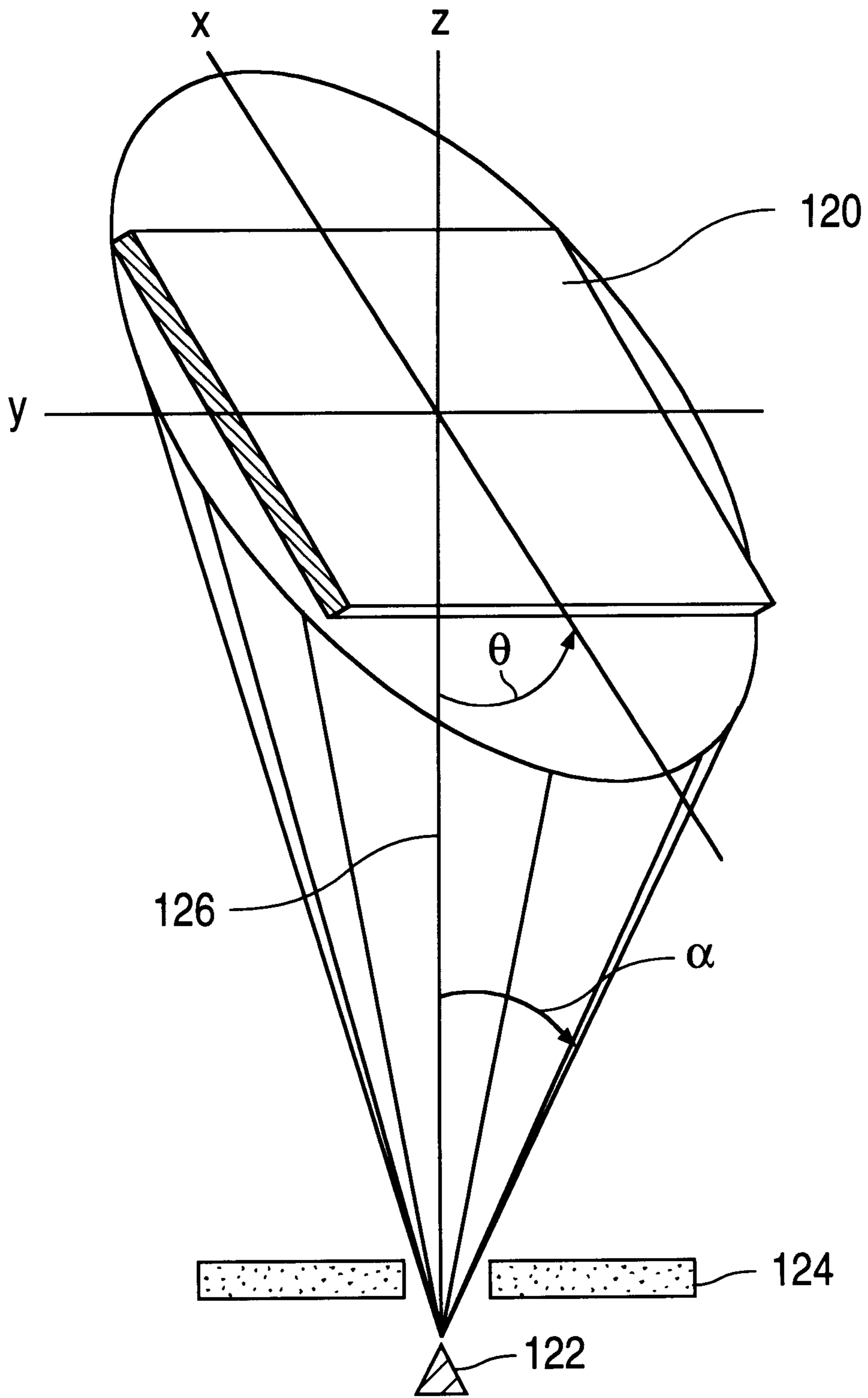
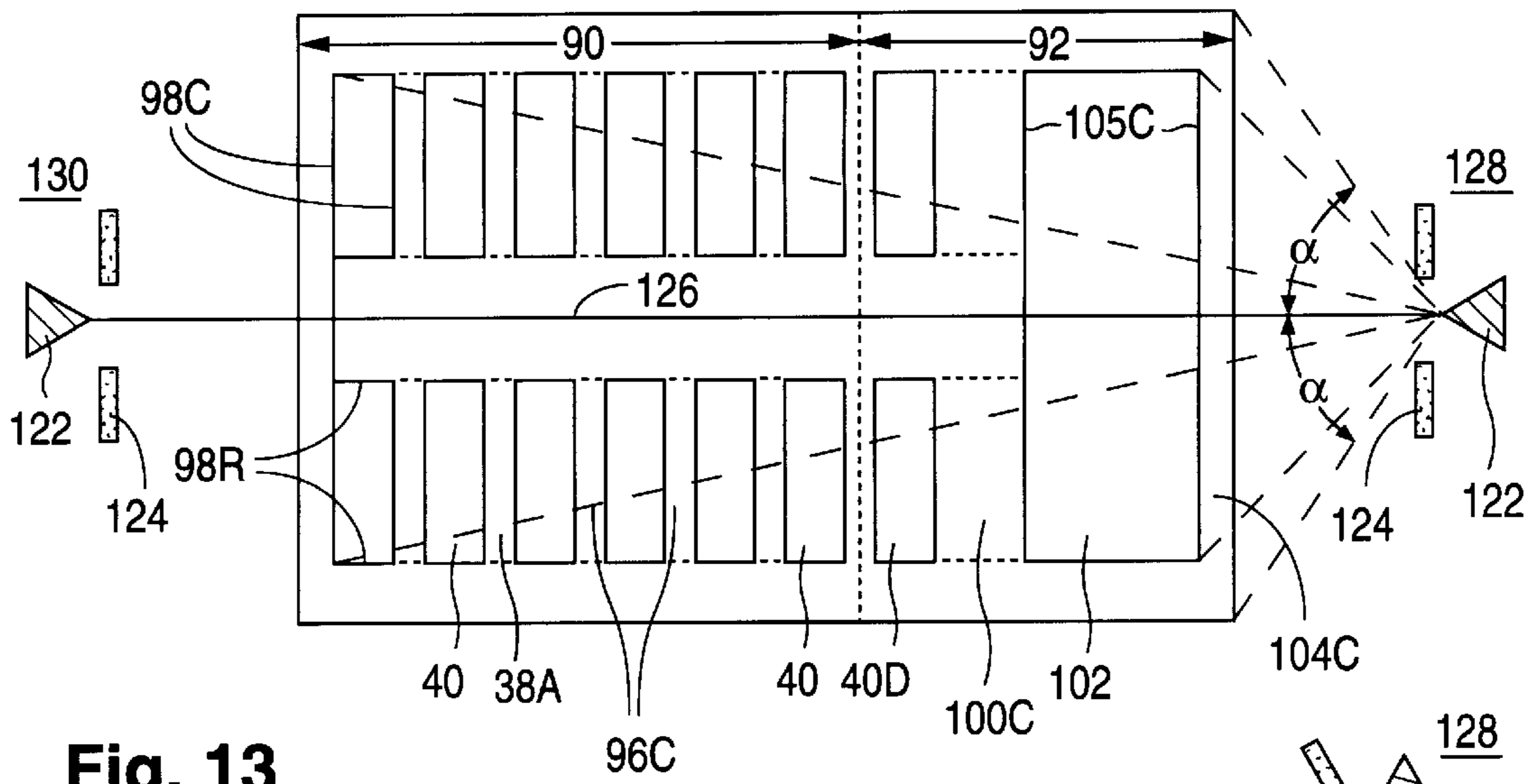
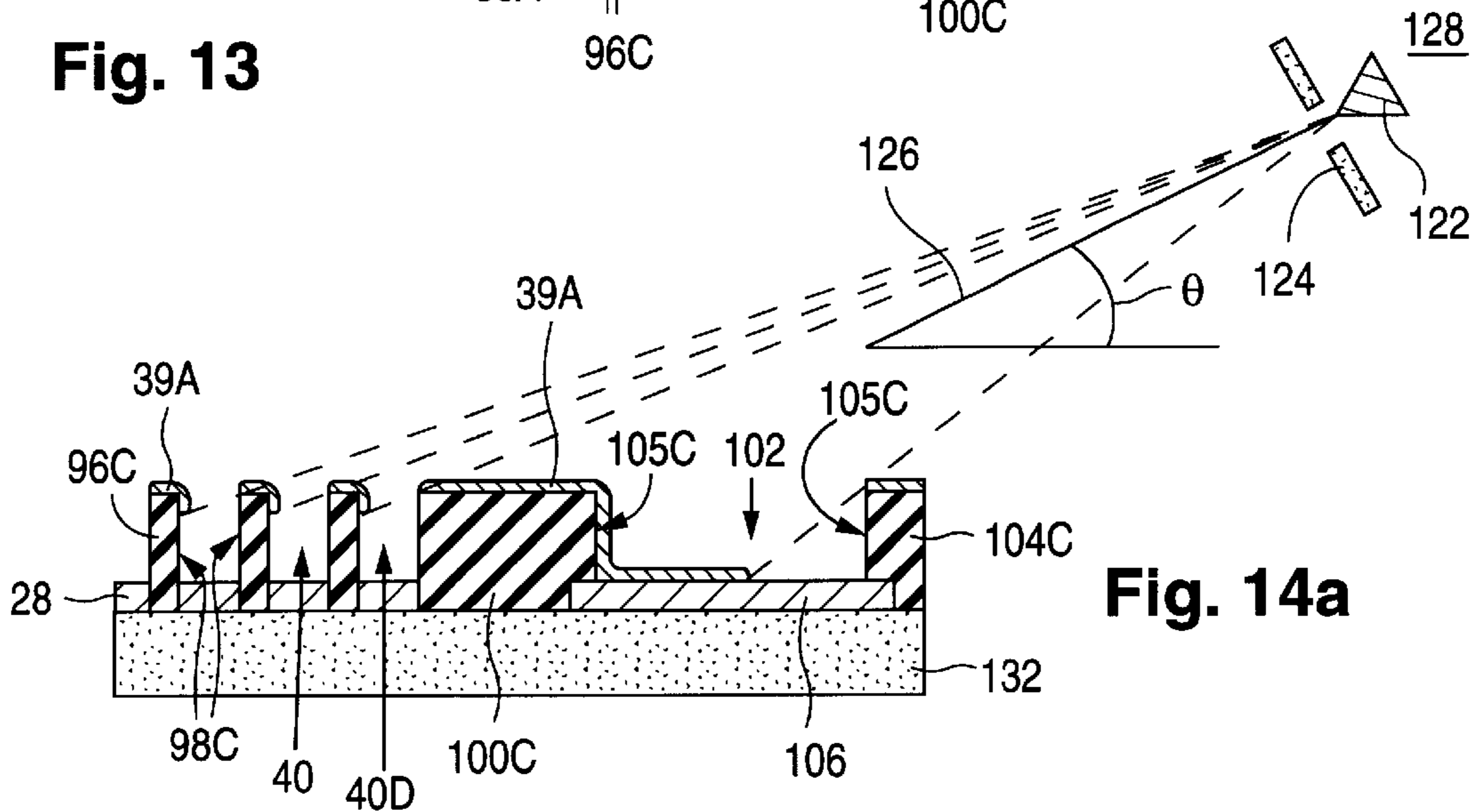


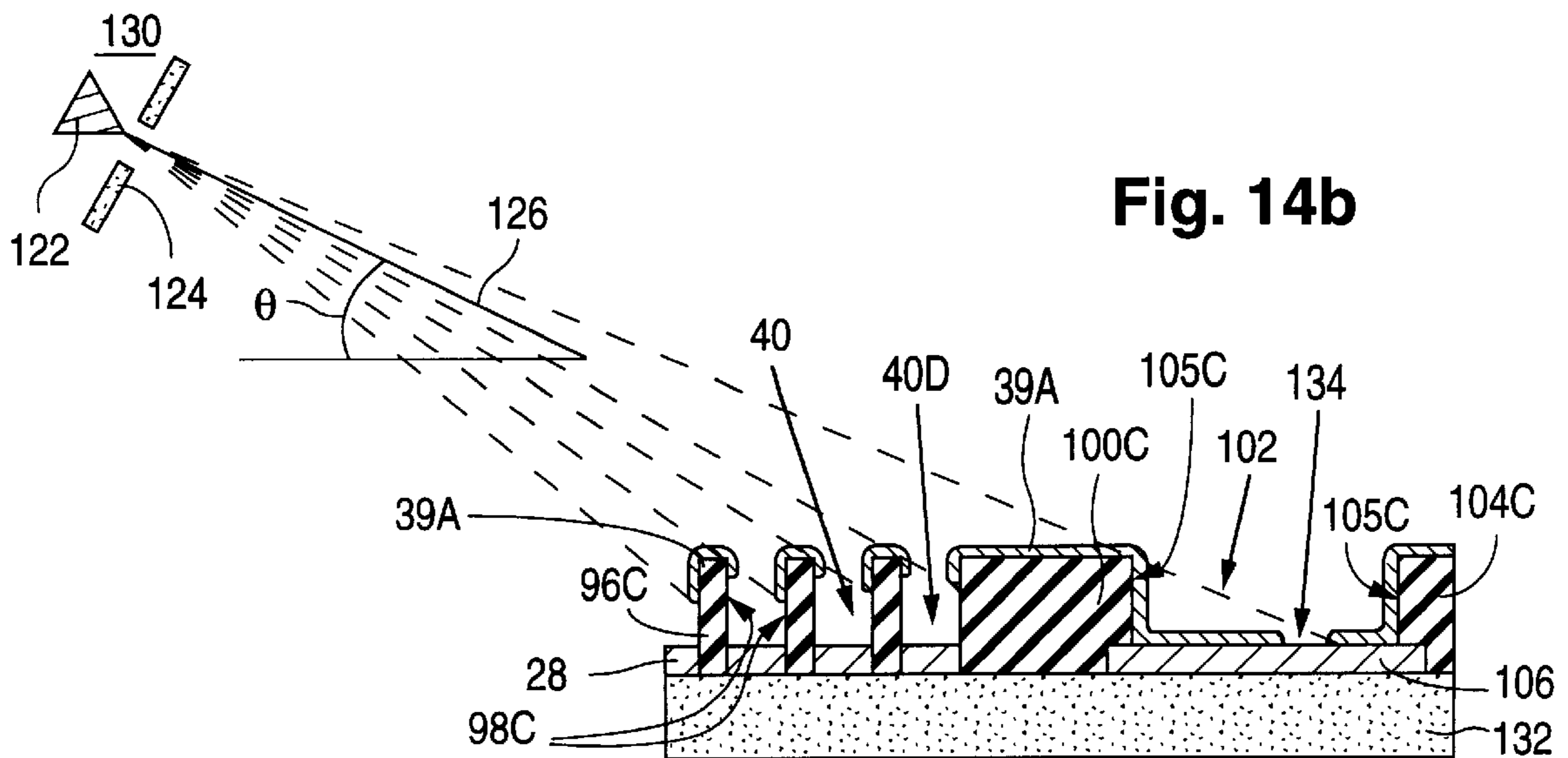
Fig. 12



**Fig. 13**



**Fig. 14a**



**Fig. 14b**

**STRUCTURE AND FABRICATION OF  
ELECTRON-EMITTING DEVICE HAVING  
FOCUS COATING CONTACTED THROUGH  
UNDERLYING ACCESS CONDUCTOR**

**CROSS REFERENCE TO RELATED  
APPLICATION**

This is related to Haven et al co-filed U.S. patent application Ser. No. 08/866,554, the contents of which are incorporated by reference to the extent not repeated herein.

**FIELD OF USE**

This invention relates to electron-emitting devices. More particularly, this invention relates to the structure and fabrication of an electron-emitting device suitable for use in a flat-panel display of the cathode-ray tube ("CRT") type.

**BACKGROUND**

FIG. 1 illustrates the basic features in the active area of a conventional color flat-panel CRT display that operates according to field-emission principles. The field-emission display ("FED") in FIG. 1 consists of an electron-emitting device and a light-emitting device. The electron-emitting device, commonly referred to as a cathode, contains electron-emissive elements 1 that emit electrons over a wide area. The emitted electrons are directed towards light-emissive elements 2 distributed over a corresponding area in the light-emitting device. Upon being struck by the electrons, light-emissive elements 2 emit light that produces an image on the viewing surface of the FED.

Specifically, electron-emissive elements 1 are situated over emitter electrodes 3, one of which is shown in FIG. 1. Control electrodes 4 cross over, and are electrically insulated from, emitter electrodes 3. A set of electron-emissive elements 1 are electrically coupled to each emitter electrode 3 where it is crossed by a control electrode 4. For simplicity, FIG. 1 depicts only one electron-emissive element 1 at each electrode crossing location. When a suitable voltage is applied between a control electrode 4 and an emitter electrode 3, that control electrode 4 extracts electrons from associated electron-emissive element 1. An anode (not shown) in the light-emitting device attracts the electrons to light-emissive elements 2 laterally separated by black matrix 5 over transparent faceplate 6.

Electron emission from a single electron-emissive element 1 under the control of associated control electrode 4 is generally distributed throughout a solid cone with a maximum half angle greater than 45° relative to the vertical in FIG. 1. For reference purposes, FIG. 1 illustrates a 45°-half angle cone at the tip of one electron-emissive element 1. At the light-emitting device, undeflected electrons are distributed over an area generally represented by item 7 in FIG. 1. Area 7 increases as the distance between the cathode and anode structures increases. As FIG. 1 illustrates, undeflected electrons emitted by one electron-emissive element 1 can strike area outside intended light-emissive element 2.

FEDs that operate at high anode voltages for improved brightness and lifetime require comparatively large cathode-to-anode spacings in order to avoid electrical arcing between components of the anode and cathode structures. The potentialities of having electrons strike undesired places, e.g., light-emissive elements 2 adjacent to intended light-emissive element 2, are therefore of special concern for FEDs operating with high anode voltages.

The electron-emitting device in an FED commonly contains a focusing system that helps control the trajectories of

the electrons so that they largely only strike the intended light-emissive elements. The focusing system normally extends above the control electrodes. The lateral relationship of the focusing system to the sets of electron-emissive elements is critical to achieving high display performance.

FIGS. 2a-2c illustrate a conventional variation of the FED of FIG. 1 to which a focusing system 8 has been added. Focusing system 8 locally deforms the electric field existing between the anode and cathode structures to form an electron lens that alters the electron trajectories. The amount of change in the electron trajectories depends on factors such as the initial trajectories, the strength of the electron lens, and the times of flight within the lens. Ideally, the characteristics of focusing system 8 are chosen in such a way that substantially all impinging electrons strike intended electron-emissive element 2 as indicated in FIG. 2a. However, the electrons often strike undesired areas when the electron lens is underfocused as shown in FIG. 2b or overfocused as shown in FIG. 2c.

The ability of the electron lens to properly focus the emitted electrons depends on the physical characteristics of the focusing system. Generally, the focusing system needs to be capable of maintaining a desired potential. U.S. Pat. No. 5,528,103 illustrates various configurations for an electron focusing system that can maintain a potential in an FED. Unfortunately, all of the focusing systems in U.S. Pat. No. 5,528,103 either provide insufficient focusing capability or raise concerns with respect to electrical short circuiting to the control electrodes.

It is desirable to have a focusing system that provides a suitable amount of electron focusing for an electron-emitting device without running any significant reliability or other short-circuiting risk. Specifically, the potential that controls the electron trajectories should be provided to the focusing system in a manner that avoids reliability concerns. It is also desirable to have a technique for readily fabricating such a focusing system.

**GENERAL DISCLOSURE OF THE INVENTION**

The present invention furnishes an electron focusing system for an electron-emitting device suitable for use in a flat-panel CRT display, especially an FED. The present electron focusing system includes a reliable, readily manufacturable arrangement configured according to the invention for receiving a potential that controls electron focusing. In a fundamental form of an electron-emitting device that employs the electron focusing system of the invention, electrons are emitted by an electron-emissive element situated in an opening in a dielectric layer. The electron-emissive element is exposed through a control opening in a control electrode that overlies the dielectric layer.

The present focusing system is formed with a base focusing structure, a focus coating, and an access electrical conductor suitable for receiving the focus control potential. The base focusing structure overlies the dielectric layer and has a focus opening that overlies the electron-emissive element. Electrons emitted by the electron-emissive element travel through the focus opening.

The focus coating overlies the base focusing structure, preferably extending only partway down into the focus opening. The focus coating is normally formed with electrically non-insulating material—i.e., material that is either electrically conductive or electrically resistive. The focus coating is also normally of lower resistivity than the base focusing structure. Consequently, the focus coating provides the large majority of focus control over the emitted electrons.

The access conductor overlies the dielectric layer and is electrically coupled to the focus coating along its lower surface, typically through an access opening in the base focusing structure. The focus control potential is provided from the access conductor to the focus coating for controlling the electron focusing.

The base focusing structure typically overlies part of the control electrode and part of the access conductor. Since both the control electrode and the access conductor overlie the dielectric layer, the access conductor is at basically the same level in the electron-emitting device as the control electrode. Hence, the focus control potential can be applied to the access conductor in largely the same way that voltage is applied to the control electrode for controlling the electron-emissive element. This improves reliability and avoids electrical connection and routing problems that could arise from attempting to contact the focus coating along its upper surface.

The control electrode and the access conductor typically consist primarily of the same electrically conductive material. In particular, the access conductor is usually formed during formation of the control electrode. Manufacturing the focusing system in this manner avoids the expenditure of fabrication time that would otherwise be needed to provide an access conductor that contacts the upper surface of the focus coating.

The focus coating is typically formed according to an angled deposition technique. That is, the focus coating is deposited over the base focusing structure at an incidence angle less than  $90^\circ$  measured relative to a plane running generally parallel to the dielectric layer. The incidence angle is normally chosen to be sufficiently small that the focus coating material accumulates only partway into the focus opening.

In an electron-emitting device, there is often a characteristic lateral direction in which electron focus control is most critical. For example, consider a situation in which the focus opening is of greater dimension in a first lateral direction than in a second lateral direction perpendicular to the first direction. Assume that focus control is more critical in the second direction than in the first direction.

If the focus coating were deposited from an angled deposition source that, relative to an electron-emitting device under fabrication, is being simultaneously rotated around the device at a largely constant incidence angle (less than  $90^\circ$ ), the greater dimension of the focus opening in the first direction would normally result in unequal accumulation of the focus coating material in the focus opening. Attempting to set the deposition incidence angle at a value that yields optimum (or near optimum) focus control in the second direction—i.e., the direction in which focus control is more critical—could lead to an undesirable result. Specifically, the focus coating material that impinges instantaneously on the focus opening with substantial lateral velocity in the first direction might reach the bottom of the focus opening and short circuit the focus coating to the control electrode even though the focus coating material that impinges instantaneously on the focus opening with substantial lateral velocity in the second direction only goes partway into the focus opening.

The foregoing problem is addressed in the invention by performing the angled focus coating deposition from a pair of suitably chosen opposite positions. As used here, a deposition “position” means a location from which material, such as the focus coating material, is directed toward a target, such as the focus opening.

The deposition from each of the opposite positions is typically characterized by a principal deposition axis. Preferably, both principal deposition axes extend roughly perpendicular to the first lateral direction mentioned above. By arranging for the two oppositely located deposition positions to be adequately far away from the focus opening and/or by suitably restricting the half angle through which the focus coating material is directed from each of the positions toward the focus opening, the focus coating material impinges on the focus opening with lateral velocity largely in the second direction. Substantially none of the focus coating material has a significant lateral velocity component in the first lateral direction. Hence, the depth to which the focus coating material penetrates into the focus opening can be set at a value particularly suitable for the particular direction, the second direction here, in which focus control is more critical without running any significant risk of short circuiting the focus coating to the control electrode.

Depositing the focus coating material from two opposite positions in the foregoing manner is fully compatible with the necessity to electrically couple the focus coating to the access conductor. For instance, when the electrical coupling is made through the access opening in the focusing structure, the access opening is normally chosen to be of greater dimension than the focus opening in the second lateral direction. With the deposition incidence angle being set at a value sufficiently small that the focus coating material accumulates only partway into the focus opening, the value of the incidence angle can, at the same time, readily be sufficiently large that the focus coating material goes deep enough into the access opening to contact the access conductor. Consequently, the focus coating is electrically coupled to the access conductor without being short circuited to the control electrode.

By translating both deposition positions in a given direction—e.g., the first direction—during the deposition from each position, formation of the focus coating over a large area is facilitated. The need for an extremely large deposition system is alleviated. The deposition parameters can be adjusted to accommodate various device sizes and resolutions. Consequently, the present deposition technique is highly flexible. In short, the invention provides a significant advance.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified cross-sectional schematic side view of a portion of a conventional electron-emitting device.

FIGS. 2a, 2b and 2c are simplified cross-sectional schematic side views of a portion of a conventional electron-emitting device having a focusing system. FIGS. 2a–2c respectively illustrate conditions of acceptable focusing, underfocusing, and overfocusing.

FIG. 3 is a cross-sectional side view of a portion of an electron-emitting device having a focusing system suitable for being electrically contacted according to the invention. The cross section of FIG. 3 is taken through plane 3–3 in each of FIGS. 4 and 5.

FIG. 4 is a plan view of the portion of the electron-emitting device in FIG. 1.

FIG. 5 is a plan view of the base focusing structure, column electrodes, and two emitter electrodes in the electron-emitting device of FIG. 3.

FIGS. 6a–6d are cross-sectional side views representing steps that employ the invention’s teachings in manufacturing the base focusing structure of the electron-emitting device in FIGS. 3–5.

FIG. 7 is a cross-sectional side view of a portion of another electron-emitting device having a focusing system suitable for being electrically contacted according to the invention.

FIG. 8 is a simplified cross-sectional side view of a portion of an electron-emitting device having an electron focusing system of the type employed in the electron-emitting device of FIG. 7. FIG. 8 shows how the focus coating of the electron focusing system is electrically contacted in accordance with the invention.

FIGS. 9–11 are simplified plan views of three variations of the electron-emitting device in FIG. 8. Each variation employs a different arrangement for contacting the focus coating according to the invention. The cross section of FIG. 8 is taken through plane 8—8 in FIG. 9.

FIG. 12 is a schematic view of an angled deposition system suitable for use in the invention.

FIG. 13 is a simplified plan view of part of the electron-emitting device of FIGS. 8 and 9 during angled deposition of the focus coating according to the invention.

FIGS. 14a and 14b are simplified cross-sectional side views representing steps that employ the invention's teachings in depositing the focus coating of the electron-emitting device in FIGS. 8 and 9.

Like reference symbols are employed in the drawings and in the description of the preferred embodiments to represent the same, or very similar, item or items.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention furnishes a matrix-addressed electron-emitting device in which electron focusing is achieved with a focus coating that receives a focus control potential by way of an access electrical conductor (a) situated at the level of control electrodes in the electron-emitting device and (b) externally accessible in largely the same manner as the control electrodes so as to improve reliability. The electron emitter of the invention typically operates according to field-emission principles in producing electrons that cause visible light to be emitted from corresponding light-emissive phosphor elements of a light-emitting device. The combination of the electron-emitting and light-emitting devices forms a cathode-ray tube of a flat-panel display such as a flat-panel television or a flat-panel video monitor for a personal computer, a lap-top computer, or a workstation.

In the following description, the term "electrically insulating" (or "dielectric") generally applies to materials having a resistivity greater than  $10^{10}$  ohm-cm. The term "electrically non-insulating" thus refers to materials having a resistivity below  $10^{10}$  ohm-cm. Electrically non-insulating materials are divided into (a) electrically conductive materials for which the resistivity is less than 1 ohm-cm and (b) electrically resistive materials for which the resistivity is in the range of 1 ohm-cm to  $10^{10}$  ohm-cm. These categories are determined at an electric field of no more than 1 volt/ $\mu\text{m}$ . Similarly, the term "electrically non-conductive" refers to materials having a resistivity of at least 1 ohm-cm, and includes electrically resistive and electrically insulating materials.

Examples of electrically conductive materials (or electrical conductors) are metals, metal-semiconductor compounds (such as metal silicides), and metal-semiconductor eutectics. Electrically conductive materials also include semiconductors doped (n-type or p-type) to a moderate or

high level. Electrically resistive materials include intrinsic and lightly doped (n-type or p-type) semiconductors. Further examples of electrically resistive materials are (a) metal-insulator composites, such as cermet (ceramic with embedded metal particles), (b) forms of carbon such as graphite, amorphous carbon, and modified (e.g., doped or laser-modified) diamond, (c) and certain silicon-carbon compounds such as silicon-carbon nitrogen.

Referring to the drawings, FIG. 3 illustrates a side cross section of part of a matrix-addressed electron-emitting device that contains an electron focusing system which can be electrically contacted according to the invention to receive a potential that controls the focusing of electrons emitted by the device. Exemplary arrangements of a mechanism by which the focusing system in the electron-emitting device of FIG. 3 is provided with the focus control potential are shown in FIGS. 8–11 described further below. The device in FIG. 3 operates in field-emission mode and is often referred to here as a field emitter. FIG. 4 depicts a plan view of the part of the field emitter shown in FIG. 3. To simplify pictorial illustration, dimensions in the vertical direction in FIG. 4 are illustrated at a compressed scale compared to dimensions in the horizontal direction.

The field emitter of FIGS. 3 and 4 is employed in a color FED divided into rows and columns of color picture elements ("pixels"). The row direction—i.e., the direction along the rows of pixels—is the horizontal direction in FIGS. 3 and 4. The column direction, which extends perpendicular to the row direction and thus along the columns of pixels, extends perpendicular to the plane of FIG. 3. The column direction extends vertically in FIG. 4. Each color pixel contains three sub-pixels, one for red, another for green, and the third for blue.

The field emitter of FIGS. 3 and 4 is created from a thin transparent flat baseplate 10 typically consisting of glass such as Schott D263 glass having a thickness of approximately 1 mm. A group of opaque parallel emitter electrodes 12 are situated on baseplate 10 and extend in the row direction to form row electrodes. Each emitter electrode 12 is, in plan view, generally shaped like a ladder consisting of a pair of rails 14 and a group of crosspieces 16 separated by emitter openings 18. Electrodes 12 are typically formed with an alloy of nickel or aluminum to a thickness of 200 nm.

An electrically resistive layer 20 is situated on emitter electrodes 12. Resistive layer 20 provides a resistance of at least  $10^6$  ohms, typically  $10^{10}$  ohms, between each emitter electrode 12 and, as described below, each overlying electron-emissive element. Layer 20 typically consists of cermet having a thickness of 0.3–0.4  $\mu\text{m}$ . A transparent dielectric layer 22 overlies resistive layer 20. Dielectric layer 22 typically consists of silicon oxide having a thickness of 0.1–0.2  $\mu\text{m}$ .

A group of laterally separated sets of electron-emissive elements 24 are situated in openings 26 extending through dielectric layer 22. Each set of electron-emissive elements 24 occupies an emission region that overlies one crosspiece 16 in each emitter electrode 12. The particular elements 24 overlying each emitter electrode 12 are electrically coupled to that electrode 12 through resistive layer 22. Elements 24 can be shaped in various ways. In the example of FIG. 3, elements 24 are generally conical in shape and typically consist of molybdenum.

A group of composite generally parallel opaque control electrodes 28 are situated on dielectric layer 22 and extend in the column direction to form column electrodes. Each control electrode 28 controls one column of sub-pixels. Three consecutive electrodes 28 thus control one column of pixels.

Each control electrode **28** consists of a main control portion **30** and a group of adjoining gate portions **32** equal in number to the number of emitter electrodes **12**. Main control portions **30** extend fully across the field emitter in the column direction. Gate portions **32** are partially situated in large control openings **34** extending through main portions **30**. Electron-emissive elements **24** are exposed through gate openings **36** in the segments of gate portions **32** situated in large control openings **34**. Inasmuch as control openings **34** laterally bound the emission regions for the sets of electron-emissive elements **24**, each control opening **34** is sometimes referred to as a “sweet spot”. Main control portions **30** typically consist of chromium having a thickness of  $0.2\ \mu\text{m}$ . Gate portions **32** typically consist of chromium having a thickness of  $0.04\ \mu\text{m}$ .

An electron focusing system **37**, generally arranged in a waffle-like pattern as viewed perpendicularly to the upper surface of faceplate **10**, is situated on the parts of main control portions **30** and dielectric layer **22** not covered by control electrodes **28**. Referring to FIG. **3**, focusing system **37** is formed with an electrically non-conductive base focusing structure **38** and a thin electrically non-insulating focus coating **39** situated over part of base focusing structure **38**. Inasmuch as focus coating **39** is thin and generally follows the lateral contour of base focusing structure **38**, only the plan view of base structure **38** of focusing system **37** is illustrated in FIG. **4**.

Non-conductive base focusing structure **38** normally consists of electrically insulating material but can be formed with electrically resistive material of sufficiently high resistivity as to not cause control electrodes **28** to be electrically coupled to one another. Non-insulating focus coating **39** normally consists of electrically conductive material, typically a metal such as aluminum having a thickness of  $100\ \text{nm}$ . Other candidates for focus coating **39** are chromium, nickel, gold, and silver. The sheet resistance of focus coating **39** is typically  $1\text{--}10\ \text{ohms/sq}$ . In certain applications, coating **39** can be formed with electrically resistive material. In any event, the resistivity of coating **39** is considerably less than that of base structure **38**.

Base focusing structure **38** has a group of openings **40**, one for each different set of electron-emissive elements **24**. In particular, focus openings **40** expose gate portions **32**. Focus openings **40** are concentric with, and larger than, large control openings (sweet spots) **34**.

In FIG. **4**, the greater dimensional compression in the column (vertical) direction than in the row (horizontal) direction causes focus openings **40** to appear longer in the row direction than in the column direction. Actually, the opposite case normally arises. The lateral dimension of openings **40** in the row direction is usually  $50\text{--}150\ \mu\text{m}$ , typically  $80\text{--}90\ \mu\text{m}$ . The lateral dimension of openings **40** in the column direction is usually  $75\text{--}300\ \mu\text{m}$ , typically  $120\text{--}140\ \mu\text{m}$ , and thus is normally significantly greater than the lateral dimension of openings **40** in the row direction.

Focus coating **39** lies on the top surface of base focusing structure **38** and extends partway, typically in the vicinity of up to  $50\text{--}75\%$  of the way, into focus openings **40**. Although non-conductive base focusing structure **38** contacts control electrodes **28**, non-insulating focus coating **39** is everywhere spaced apart from control electrodes **28**. As viewed perpendicularly to the upper surface of baseplate **10**, each different set of electron-emissive elements **24** is laterally surrounded by base structure **38** and thus by coating **39**.

Focusing system **37**, primarily non-insulating focus coating **39**, focuses electrons emitted from each set of electron-

emissive elements **24** so that the electrons impinge on phosphor material in the corresponding light-emissive element of the light-emitting device situated opposite the electron-emitting device. In other words, focusing system **37** focuses electrons emitted from electron-emissive elements **24** in each sub-pixel so as to strike phosphor material in the same sub-pixel. Efficient performance of the electron focusing function requires that coating **39** extend considerably above elements **24** and that certain lateral distances from each set of elements **24** to certain parts of system **37**, specifically certain parts of coating **39**, be controlled well.

More particularly, pixels are typically largely square with the three sub-pixels of each pixel being arranged in a line extending in the row direction. Portions of the active pixel area between rows of pixels are typically allocated for receiving edges of spacer walls. As a result, large control openings **34** are typically considerably closer together in the row direction than in the column direction. Better focus control is thus necessary in the row direction than in the column direction. Accordingly, the critical distances that need to be controlled to achieve good electron focusing are the row-direction distances from lateral edges of focusing system **37** to the nearest edges **34C** of large control openings **34**. Since edges **34C** extend in the column direction, they are referred to here as column-direction edges.

The internal pressure in the FED that contains the field emitter of FIGS. **3** and **4** is very low, generally in the vicinity of  $10^{-7}\text{--}10^{-6}$  torr. With baseplate **10** being thin, focusing system **37** also serves as a surface contacted by spacers, typically spacer walls, that enable the FED to resist external forces such as air pressure while maintaining a desired spacing between the electron-emitting and light-emitting parts of the display.

The preceding distance and spacer-contact considerations are addressed by configuring base focusing structure **38** as a tall main base portion **38M** and a group of opposing pairs of critically aligned further base portions **38L**. The two further base focusing portions **38L** in each of the opposing pairs of further base portions **38L** are situated on opposite sides of a corresponding one of large control openings **34**. In the example of FIG. **3**, further base focusing portions **38L** are slightly shorter than main base focusing portion **38M**. Parts of focus coating **39** extend partway down the sidewalls of shorter focusing portions **38L** into focus openings **40**.

Each pair of opposing shorter base focusing portions **38L** have lateral column-direction edges **38C** vertically aligned to portions **28C** of the outer lateral longitudinal edges of the particular control electrode **28** that controls the corresponding set of electron-emissive elements **24**. The row-direction distances from each pair of control-electrode edge portions **28C**, and therefore from the corresponding pair of focusing-structure column-direction edges **38C**, to the column-direction edges **34C** of large control opening **34** for the corresponding set of electron-emissive elements **24** are determined by fixed photomask dimensions and are therefore well controlled. Hence, the portions of focus coating **39** overlying each pair of opposing focusing portions **38L** are spaced apart from the corresponding set of electron-emissive elements **24** by well-controlled row-direction distances.

The full plan-view configuration of base focusing structure **38** with respect to electrodes **28** and **12** can be seen in FIG. **5** oriented the same as FIG. **4**. FIG. **5** depicts two emitter electrodes **12**. Item **42** in FIG. **5** indicates the area between each pair of consecutive electrodes **12**. During display assembly, spacer walls are brought into contact with parts of focus coating **39** overlying main focusing portion

**38M** generally along some or all of areas **42**. If desired, strips of main focusing portion **38M** above spacer-contact areas **42** can be replaced with focusing material that extends to approximately the same height as shorter focusing portions **38L** so as to provide grooves in base focusing portion **38**, as covered there with focus coating **39**, for receiving edges of the spacer walls.

Base focusing structure **38** is normally created from negative-tone electrically insulating actinic material which is selectively exposed to actinic radiation and developed. The actinic material is preferably photo-polymerizable polyimide, typically Olin OCG7020 polyimide. Main focusing portion **38M** typically extends 45–50  $\mu\text{m}$  above dielectric layer **22**. Further focusing portions **38L** are normally 10–20% shorter than main portion **38M**.

During display operation, a suitable potential is applied to focusing system **37**, specifically to focus coating **39**, to control the electron focusing. The focus control potential is of such a value, typically 25–50 volts relative to ground, as to cause electrons emitted from each set of electron-emissive elements **24** to be focused on the corresponding (directly opposite) phosphor region in the light-emitting device. As indicated above, examples of a mechanism for providing the focus control potential to focus coating **39** are described below in conjunction with FIGS. 8–11.

The field emitter of FIGS. 3–5 is typically fabricated in the following manner. A blanket layer of the emitter-electrode material is deposited on baseplate **10** and patterned using a suitable photoresist mask to produce ladder-shaped emitter electrodes **12**. Resistive layer **20** is deposited on top of the resultant structure. Dielectric layer **22** is deposited on resistive layer **20**.

A blanket layer of the electrically conductive material for main control portions **30** is deposited on layer **22** and patterned using a suitable photoresist mask to form main control portions **30**, including control openings **34**. As discussed further below, the access conductor or conductors that provide focus coating **39** with the focus control potential are normally created from this blanket control layer during the patterning step. The photoresist mask is created from a photomask (reticle) bearing the desired pattern for main control portions **30**, including openings **34**.

A blanket layer of the gate material is deposited on top of the structure and patterned using another photoresist mask to form gate portions **32**. Gate openings **36** and dielectric openings **26** are created respectively in gate portions **32** and dielectric layer **22** according to a charged-particle tracking procedure of the type described in U.S. Pat. Nos. 5,559,389 or 5,564,959. The contents of these two patents are incorporated by reference herein. Electron-emissive elements **24** are created as cones by depositing electrically conductive material through gate openings **36** and into dielectric openings **26** according to a deposition technique of the type described in either of these patents.

Base focusing structure **38** is now formed as illustrated in FIGS. 6a–6d. A primary blanket layer **38P** of negative-tone electrically insulating actinic material is provided on top of the structure. The electron-emitting structure is subjected to backside actinic radiation **46** that impinges on the lower surface of baseplate **10** as shown in FIG. 6b.

Baseplate **10** and dielectric layer **22** largely transmit backside radiation **46** while resistive layer **20** directly transmits a substantial percentage of radiation **46**, typically in the vicinity of 40–80%. Electrodes **12** and **28** are largely non-transmissive of radiation **46**. Hence, the portion **38Q** of primary actinic layer **38P** not shadowed by electrodes **12** and

**28** is exposed to radiation **46** and changes chemical structure. In so doing, radiation **46** passes through emitter openings **18**. Sections of primary layer **38P** vertically aligned with lateral control-electrode edges **28C** are thereby exposed to radiation **46** to define column-direction lateral edges **38C** of base focusing structure **38**.

The partially finished structure is now subjected through a photomask **47** to frontside actinic radiation **48** that impinges on top of the structure. See FIG. 6c. Photomask **47** has radiation-blocking areas **47B** at regions above focus openings **40**. Each of blocking areas **47B** corresponds to the region indicated by horizontal arrow **44** and vertical arrow **40** in FIG. 3 or 4.

As discussed further below, photomask **47** has an additional radiation-blocking area (not shown) above each of the one or more locations where focus coating **39** is to extend along the thickness of base focusing structure **38** to contact the corresponding access conductor created from the blanket control layer utilized in creating main control portions **30**. The primary actinic material below these additional radiation-blocking areas overlies the access conductor or conductors and thus has not been exposed to backside radiation **46**. Material of primary layer **38P** not shadowed by blocking areas **47B** and the additional blocking area is exposed to frontside radiation **48** and changes chemical structure.

The order in which the backside and frontside exposures are performed is generally immaterial. When the actinic material is photo-polymerizable polyimide, such as Olin OCG7020 polyimide, the actinic radiation during both exposures is typically UV light that causes the exposed polyimide to polymerize.

A development operation is performed to remove the unexposed portions of primary layer **38P**, thereby producing base focusing structure **38** and focus openings **40** as shown in FIG. 6d. Each opening (not shown) which penetrates base focusing structure **38** for enabling focus coating **39** to contact the corresponding access conductor is formed at the same time. Due to the presence of baseplate **10**, backside radiation **46** normally did not fully penetrate primary layer **38P** at the backside exposed areas. Since further base focusing portions **38L** were only exposed to backside radiation **46**, focusing portions **38L** are normally shorter than main focusing portion **38M**.

Focus coating **39** is formed over base focusing structure **38** by performing a suitable angled evaporation of the focus coating material. Further information on the angled evaporation is given below. This completes the formation of focusing system **37**, thereby yielding the field emitter of FIGS. 3–5.

In subsequent operations, the field emitter is sealed to the light-emitting device through an outer wall. The sealing operation typically entails mounting the outer wall and the spacer walls on the light-emitting device. This composite assembly is then brought into contact with the field emitter and hermetically sealed in such a manner that the internal display pressure is typically  $10^{-7}$ – $10^{-6}$  torr. The spacer walls contact focusing system **37** along part or all of areas **42** in FIG. 5.

The field emitter of FIGS. 3–5 typically has further lateral dimensions of the magnitude disclosed in, and is fabricated according to the further process information presented in, Spindt et al, co-filed U.S. patent application Ser. No. 08/866, 150, the contents of which are incorporated by reference herein.

FIG. 7 illustrates a side cross section of part of a matrix-addressed gated field emitter that contains a focusing system



37A similar to focusing system 37. The field emitter of FIG. 7 is otherwise largely the same, and is fabricated in largely the same way, as the field emitter of FIGS. 3–5.

Focusing system 37A in FIG. 7 is created by processing negative-tone primary actinic layer 38P in an alternative way that involves first exposing primary layer 38P to frontside actinic radiation 48 through a photomask having radiation-blocking stripes that extend in the row direction fully across the display's intended active area. As with photomask 47, the photomask has an additional radiation-blocking area above each intended location where the focus coating is to extend along the thickness of the base focusing structure to contact the corresponding access conductor. Frontside radiation 48 fully penetrates layer 38P at the exposed areas, causing the so-exposed actinic material below the row-direction radiation-blocking stripes and the additional radiation-blocking areas to change chemical structure.

The exposure with backside radiation 46 is now performed so that radiation 46 partially penetrates primary layer 38P at the exposed areas. The only unexposed primary actinic material subjected to radiation 46 (and thus not shadowed by electrodes 12 and 28) consists of the rectangular column-direction primary actinic strips situated between the intended locations for focus openings 40 in each focus opening row. Consequently, the exposed material of primary layer 38P has column-direction edges 38E vertically aligned to portions of control-electrode column-direction edges 28C generally at the locations for column-direction focus edges 38C in FIGS. 3 and 4.

Primary layer 38P is now developed to remove the unexposed actinic material. The exposed remainder of layer 38P forms an electrically non-conductive base focusing structure 38A having focus openings 40. Base focusing structure 38A also has an access opening (not shown) at each location where the focus coating is to contact the underlying access conductor. Because backside radiation 46 only partially penetrated primary layer 38P at the backside-exposed areas, the height of the full widths of the column-direction rectangular focusing strips between focus openings 40 is both largely uniform and less than the height of the remainder of base focusing structure 38A. Except for this and the fact that focus openings 40 here are, in plan view, more rectangular than openings 40 in FIG. 4, the shape of base structure 38A is generally the same as that shown for base structure 38 in FIGS. 3 and 4.

As with the backside exposure in the process of FIGS. 6a–6d, the backside exposure in this alternative process can be performed under such conditions that backside radiation 46 fully penetrates primary actinic layer 38P at the exposed areas. The height differential between (a) the column-direction rectangular focusing strips situated between focus openings 40 in each focus opening row and (b) the remainder of base focusing structure 38A is then reduced or eliminated.

Base focusing structure 38A is provided with an electrically non-insulating focus coating 39A analogous to focus coating 39 to form focusing system 37A. Focusing coating 39A typically consists of electrical conductive material evaporatively deposited in the manner employed for creating focus coating 39. The resultant field emitter appears generally as shown in FIG. 7. Items 38T and 39T respectively indicate the top surfaces of the taller material of base focusing structure 38A and focus coating 39A elsewhere in the device.

Focusing system 37 or 37A forms an electron focusing lens whose characteristics are largely defined by the lens

dimensions. A basic understanding of how the lens dimensions affect the electron focusing is facilitated with reference to the field emitter of FIG. 7 in which the top surface of focus coating 39A is relatively flat. Items 80, 82, and 84 in FIG. 7 indicate the pertinent lens dimensions. The electron lens in the field emitter of FIGS. 3–5 operates in a similar manner to that of FIG. 7.

The time of flight within the electron lens is basically the time during which emitted electrons are strongly under the influence of the lens. Referring to FIG. 7, the time of flight for the lens formed with focusing system 37A is the distance 80 that focus coating 39A extends vertically along the column-direction sidewalls of base focusing structure 38A in focus openings 40.

The determinant for the entry point of an electron into the lens is the vertical distance 82 from the top of column electrodes 28 to the bottom of focus coating 39A along the column-direction sidewalls of base focusing structure 38A in focus openings 40. Although the variation in height of the upper surface of column electrodes 28 is a large fraction of entry-point distance 82 at the illustration scale employed in FIG. 7, the actual height variation in the upper surface of electrodes 28 is a small fraction of entry-point distance 82 and can be largely ignored insofar as the entry-point determinant is concerned. In general, flat-panel display performance improves as entry-point distance 82 is reduced. Accordingly, distance 82 is typically made as small as can be tolerated without running a substantial risk of short circuiting focus coating 39A to electrodes 28.

A third determinant of the electron focusing lens is the lateral half width across which the lens locally influences electrons passing through each focus opening 40. In the field emitter of FIG. 7, the lateral half width for each focus opening 40 is the row-direction distance 84 from focus coating 39A in that focus opening 40 to the row-direction center of column electrode 28 in that opening 40. Lateral half width 84 should be a large fraction of the row-direction distance 86 from the row-direction center of the column-direction strip of base focusing structure 38A along each focus opening 40 to the row-direction center of column electrode 28 in that opening 40. Lens aberration that can lead to undesirable electron trajectories is reduced when lateral half width 84 is a large fraction of row-direction distance 86.

FIG. 8 depicts how the field emitter of FIG. 7 appears along the periphery of rectangular active region 90 at a location where electrical contact is made to focus coating 39A for applying the focus control potential to focusing system 37A. Item 92 in FIG. 8 is the peripheral region where (among other things) coating 39A is electrically contacted along its lower surface to receive the focus control potential.

A simplified plan view of active region 90 and peripheral region 92 is presented in FIG. 9. Item 38B in FIG. 9 is the lateral boundary of base focusing structure 38A. Item 94 indicates the location where a typical spacer wall contacts focus coating 39A (not separately indicated in FIG. 9) to separate the electron-emitting and light-emitting parts of the FED.

The portion of base focusing structure 38A in active region 90 consists of multiple row-direction strips 96R that intersect multiple column-direction strips 96C to define focus openings 40. Three row-direction strips 96R are indicated in FIG. 9 with location 94 for a spacer wall lying above the middle one of strips 96R. Although not evident in FIG. 9, row-direction strips 96R are typically taller than column-direction strips 96C. Each focus opening 40 is formed by the enclosed space where a pair of opposing

row-direction focus sidewalls **98R** of two consecutive row-direction strips **96R** respectively meet a pair of opposing column-direction focus sidewalls **98C** of two consecutive column-direction strips **96C**.

Peripheral region **92** contains a column of dummy sub-pixels adjacent to each of the first and last columns of real sub-pixels in active region **90**. The dummy sub-pixels are employed in testing the FED. Each column of dummy sub-pixels contains a dummy column electrode **28D** formed with a dummy main column portion **30D** and a group of dummy gate portions **32D**. Each dummy sub-pixel has a dummy focus opening **40D** that extends through base focusing structure **38A**. Each dummy focus opening **40D** is bounded in the row direction by one of row-direction strips **96C** and a wider column-direction strip **100C** of base structure **38A**. In the column direction, a pair of row-direction strips **96R** bound each dummy focus opening **40D**. While each dummy sub-pixel contains one crosspiece **16** of a row electrode **12**, the dummy sub-pixels do not have any electron-emissive elements.

A group of access openings (or vias) **102** extend through base focusing structure **38A** next to the last column of dummy sub-pixels. One access opening **102** is provided for multiple rows of sub-pixels, typically in the vicinity of twenty sub-pixel rows. One opening **102** is located between each pair of spacer wall locations **94**.

Access openings **102** are bounded in the row direction by column-direction strip **100C** and a column-direction strip **104C** of base focusing structure **38A**. In the column direction, each access opening **102** is bounded by a pair of row-direction strips **96R**. Each opening **102** is thus formed by the enclosed space where a pair of opposing sidewalls **98R** of two row-direction strips **96R** respectively meet opposing column-direction sidewalls **105C** of column-direction strips **100C** and **104C**. Openings **102** are of greater dimension in the row direction than focus openings **40**. When focus openings **40** are 50–100  $\mu\text{m}$ , typically 80–90  $\mu\text{m}$ , in the row-direction, access openings **102** are 80–500  $\mu\text{m}$ , typically 120–140  $\mu\text{m}$ , in the row direction.

Focus coating **39A** extends into access openings **102** sufficiently deep to contact an access electrical conductor **106** situated on dielectric layer **22** at the bottoms of openings **102**. Access conductor **106** thus contacts the lower surface of coating **39A**. At the minimum, coating **39A** extends fully down left-hand sidewall **105C** of each opening **102** to contact conductor **106**. Coating **39A** also typically extends fully down right-hand sidewall **105C** of each opening **102** to contact conductor **106**. This, however, is not essential provided that contact of coating **39A** to conductor **106** is made along left-hand sidewall **105C**.

FIG. **8** indicates that focus coating **39A** contacts the entire portion of access conductor **106** situated at the bottom of illustrated access opening **102**. This is desirable but likewise not essential. In other words, there may be a gap in coating **39A** at the bottom of each opening **102**, again provided that coating **39A** contacts conductor **106** along left-hand sidewall **105C**. Similarly, coating **39A** preferably, but not necessarily, extends fully down row-direction sidewalls **98R** of each opening **102** to contact conductor **106**. It is generally desirable to maximize the contact area between conductor **106** and coating **39A**, and to minimize the size of any gap in the portion of coating **39A** within each opening **102**.

Focus coating **39A** overlies base focusing structure **38A** everywhere in the area within boundary **38B** except along the lower portions of focus openings **40** (and dummy focus openings **40D**). Consequently, the connection of coating

**39A** to access conductor **106** within access openings **102** ensures that all the focus coating portions in focus openings **40** are electrically connected to conductor **106**.

The connection of focus coating **39A** to access conductor **106** through multiple access openings **102** separated by spacer wall locations **94** provides redundancy in case the act of bringing a spacer wall into contact with coating **39A** at any location **94**, or the subsequent pressure of a spacer wall on coating **39A**, causes a break in coating **39A**. If such a break occurs at location **94** below a spacer wall, access conductor **106** remains intact and allows the focus control potential to be supplied to the portions of coating **39A** on both sides of the break. Accordingly, all of coating **39A** receives the focus coating potential despite the occurrence of one or more breaks in coating **39A** at spacer wall locations **94**.

Access conductor **106** extends beyond base focusing structure boundary **38B** in the column direction as shown in FIG. **9**. Preferably, both ends of conductor **106** extend beyond boundary **38B** to locations where the focus control potential is supplied to conductor **106** for transmission to focus coating **39A**. The focus control potential is typically provided from a voltage source located outside the sealed low-pressure enclosure formed by the electron-emitting and light-emitting devices and the outer FED wall. As with row electrodes **12** and column electrodes **28** (including dummy column electrodes **28D**), conductor **106** thus extends through the outer FED wall.

Access conductor **106** and access openings **102** are formed during the steps utilized to fabricate the elements of active region **90**. In particular, conductor **106** is created from part of the blanket layer of conductive column material utilized to form main column portions **30** (and dummy main column portions **30D**). Openings **102** are created in base focusing structure **38A** during the formation of focus openings **40** (and dummy focus openings **40D**). Accordingly, the formation of conductor **106** and openings **102** does not require any additional processing steps.

FIGS. **10** and **11** illustrate a pair of alternative plan views for active region **90** and peripheral region **92** in the field emitter of FIG. **7**. Active region **90** in FIGS. **10** and **11** is basically the same as in FIG. **9**. Focus coating **39A** (not separately indicated in FIG. **10** or **11**) again overlies base focusing structure **38A** everywhere in the area included within boundary **38B**, except along the lower portions of focus openings **40** (and dummy focus openings **40D**).

The main difference between the field emitter of FIGS. **8** and **9** and the field emitter of FIG. **10** is that the electrically conductive material which supplies the focus control potential to focus coating **39A** contacts coating **39A** along boundary **38B** in FIG. **10** rather than through opening **102** as in FIGS. **8** and **9**. Specifically, coating **39A** extends down the sidewalls of both of the column-direction portions of boundary **38B** to respectively electrically contact a pair of access electrical conductors **108**. Although not evident in FIG. **10**, access conductors **108** lie on dielectric layer **22**. Conductors **108** partially underlie base focusing structure **38A** and extend longitudinally in the column direction. Both ends of each conductor **108** extend beyond boundary **38B** in the column direction to a location where the focus control potential is applied. As with access conductor **106**, each conductor **108** normally penetrates the outer FED wall to receive the focus control potential from an external source.

The field emitter in FIG. **11** contains multiple access openings **102** as in the field emitter of FIGS. **8** and **9**. However, instead of being connected to access conductor

106 through openings 102, focus coating 39A in FIG. 11 extends through openings 102 to electrically contact a redundancy access electrical conductor 110 at the bottoms of openings 102. Redundancy access conductor 110 is situated on dielectric layer 22 below the bottom level of base focusing structure 38A but typically does not extend beyond boundary 38B. Access conductor 110 is further connected to coating 39A along the bottoms of a pair of finger-shaped access openings 112 extending through base structure 38A near the upper and lower right-hand corners of structure 38B in FIG. 11.

Another pair of finger-shaped access openings 114 extend through base focusing structure 38A near the upper and lower left-hand corners of the field emitter in FIG. 11. Focus coating 39A extends through access openings 114 to respectively contact a pair of access electrical conductors 116 situated on dielectric layer 22 below the bottom level of base structure 38A. In contrast to access conductor 110, access conductors 116 extend beyond boundary 38B to locations where the focus control potential is provided to conductors 116.

Access conductors 110 and 116 all contact focus coating 39A along its lower surface. The finger-shaped nature of access openings 112 and 114, located in peripheral region 92 along with access opening 102, increases the area that coating 39A extends down the sidewalls of openings 112 and 114 to appropriately contact conductors 110 and 116.

The connection of either access conductor 116 through corresponding access opening 114 is normally sufficient to provide the focus control potential to focus coating 39A. Should a break occur in coating 39A along any spacer wall location 94 as a result of a spacer wall being brought into contact with coating 39A at that location 94 or due to the subsequent pressure of the spacer wall on coating 39A, the combination of access conductor 110 and access openings 102 and 112 provides redundancy to overcome the break. Specifically, the portion of coating 39A extending in the row direction from either opening 114 to opening 112 in line with that opening 114 enables the focus control potential to be transmitted to the right-hand side of coating 39A. The connection of conductor 110 to coating 39A by way of openings 102 and either one of openings 112 then allows the focus control potential to bypass the focus coating break in the manner described above for the field emitter of FIG. 9. All the portions of coating 39A thus receive the focus control potential.

In the field emitter of FIG. 10, access conductor 108 is created from the main column layer utilized in forming control electrodes 28. The same applies to access conductors 110 and 116 in the field emitter of FIG. 11. Access openings 112 and 114 in the field emitter of FIG. 11 are formed at the same time as focus openings 40. As with the field emitter of FIGS. 8 and 9, fabrication of the mechanism that provides the focus control potential to focus coating 39A in the field emitter of FIG. 10 or 11 does not require any process steps beyond those already needed for the elements in active region 90.

A vacuum metallization system suitable for performing an angled metal evaporation to create focus coating 39 or 39A is shown in FIG. 12. Item 120 in FIG. 12 represents the partially finished field emitter. Field emitter 120 is situated along the xy plane of an xyz coordinate system. The approximate center of the upper surface of field emitter 120 is at the center of the xyz coordinate system.

The focus coating metal is provided from an evaporative metal source 122 located a relatively long (lateral) distance

from field emitter 120. Metal source 122 is here treated as approximating a point source located in the xz plane. Atoms of the focus coating metal evaporate from source 122 and pass through an aperture in an aperture plate 124. The principal axis 126 of the evaporated metal atoms lies in the xz plane and thus is perpendicular to the y axis.

The aperture in plate 124 limits the distribution of the evaporated metal atoms largely to a solid cone of half angle  $\alpha$  relative to principal deposition axis 126. The value of half angle  $\alpha$  is chosen so as to be consistent with depositing the focus coating metal across the entire upper surface of base focusing structure 38A subject to any variations in the height of the upper surface of base structure 38A. Angle  $\alpha$  is usually in the range of 1–5°. For a deposition area of lateral dimensions 340 mm by 320 mm with a height variation of 10  $\mu\text{m}$ ,  $\alpha$  is typically 3°.

Incidence angle  $\theta$  is the angle between the x axis (of field emitter 120) and principal deposition axis 126. The value of incidence angle  $\theta$  depends on various factors including the depth of focus openings 40 (i.e., the height of column-direction strips 96C between openings 40), the nominal depth to which the focus coating metal enters openings 40, the minimum and maximum depths to which the focus coating metal can enter openings 40 with acceptable display performance, the dimension of openings 40 in the row direction, possibly the dimension of openings 40 in the column direction, the depth of additional openings 102 or 112 and 114, the dimensions of openings 102 or 112 and 114 in the row direction, possibly the dimensions of openings 102 or 112 and 114 in the column direction, and the nominal thickness of focus coating 39 or 39A. Incidence angle  $\theta$  is usually in the range of 5–25°. For the field emitter of FIGS. 8 and 9 at a typical value of 80–90  $\mu\text{m}$  and 120–140  $\mu\text{m}$  for the respective row-direction dimensions of focus openings 40 and access openings 102, and for a maximum metallization depth of approximately 25  $\mu\text{m}$  into focus openings 40 at a focus coating thickness of 50  $\mu\text{m}$ ,  $\theta$  is typically 15°.

The angled evaporative focus metal deposition with the system of FIG. 12 is conducted in such a manner that focus coating 39A is formed on substantially the entire top surface of base focusing structure 38A but only partway into each focus opening 40. No part of the focus coating metal should accumulate deep enough along any sidewall of any focus opening 40 so as to electrically short coating 39A to any column electrode 28.

For the field emitter of FIGS. 8 and 9, the angled deposition is also performed in such a manner that focus coating 39A extends sufficiently far down at least one of the sidewalls of each access opening 102 to contact access conductor 106, preferably down at least left-hand sidewall 105C. Similar remarks apply to the field emitter of FIG. 11 with respect to the angled deposition into access openings 112 and 114 to contact conductors 110 and 116. The angled deposition for the field emitter of FIG. 10 is performed in such a way that coating 39A extends far enough down the right-hand and left-hand edges of base focusing structure boundary 38B to contact access conductors 108.

Subject to the requirements given in the preceding two paragraphs, the angled deposition of focus coating 39A can be performed in various ways with system 122/124 of FIG. 12. For example, if focus openings 40 are approximately square or circular as viewed perpendicularly to baseplate 10, the angled deposition can be performed as system 122/124 is rotated around the field emitter, or vice versa. The value of incidence angle  $\theta$  is chosen so as to avoid having any of the focus coating metal reach the bottom of any of openings

40. With this rotational technique, at least one lateral dimension of access opening 102 in the field emitter of FIGS. 8 and 9 or at least one lateral dimension of access openings 112 and 114 in the field emitter of FIG. 11 must sufficiently exceed the diameter of focus openings 40 that the focus coating metal reaches the bottoms of openings 102 or 112 and 114 at the chosen  $\theta$  value. The rate at which system 122/124 rotates relative to the field emitter can be constant or variable.

Focus openings 40 are often of significantly greater dimension in one major lateral direction than in the transverse lateral direction. If the angled deposition is done according to the rotational technique at a constant  $\theta$  value, the consequence of openings 40 being of significantly greater lateral dimension in one lateral direction than in the transverse lateral direction is that the focus coating metal accumulates to significantly unequal depths in openings 40. In some situations, this unequal accumulation can lead to a significant risk of short circuiting focus coating 39 or 39A to control electrodes 28.

For example, focus openings 40 are typically 80–90  $\mu\text{m}$  in the column direction and 120–140  $\mu\text{m}$  in the row direction. Referring to FIG. 9, column-direction sidewalls 98C of openings 40 are thus significantly longer than row direction sidewalls 98R of openings 40. Assuming that incidence angle  $\theta$  is held constant, performing the angle deposition of coating 39A while the field emitter is being rotated relative to deposition system 122/124 results in the focus coating metal accumulating deeper into openings 40 along row-direction sidewalls 98R than column-direction sidewalls 98C.

As mentioned above, the value of entry-point distance 82 in FIG. 7 needs to be small (compared to the sum of distances 80 and 82) to achieve good electron focusing. A small value of entry-point distance 82 corresponds to focus coating 39A extending deep into focus openings 40 along column-direction sidewalls 98C. If the angled focus metal deposition is done according to the rotational technique at a constant  $\theta$  value, attempting to make entry-point distance 82 small can lead to short circuiting between column electrodes 28 and focus coating 39A along row-direction sidewalls 98R because accumulation of the focus coating metal into openings 40 is deeper along sidewalls 98R than along sidewalls 98C.

Another way of performing the angled evaporative deposition is to deposit the focus coating metal from two static positions on opposite sides of the field emitter. By appropriately choosing the locations for these two static positions, the possibility of short circuiting focus coating 39 or 39A to control electrodes 28 due to focus openings 40 being of significantly greater dimension in one major lateral direction than in the transverse lateral direction is substantially avoided. In general, the opposite-position technique entails arranging the evaporative deposition system so that, in each of the positions, the principal deposition axis is roughly perpendicular to the lateral direction in which focus openings 40 are of maximum dimension. For the typical case in which openings 40 are of greater dimension in the column direction than in the row direction, the principal deposition axis for each of the opposite positions is roughly perpendicular to the column direction.

Some azimuthal (yaw) variation—i.e., angular variation about the vertical—in the angle between each principal deposition axis and the lateral direction of maximum focus opening dimension is tolerable and, in some cases, desirable. For example, when row-direction strips 96R are taller than

column-direction strips 96C, the amounts of focus coating metal that accumulate on the portions of row-direction sidewalls 98R extending from the tops of row direction strips 96R down to the tops of column-direction strips 96C are comparatively small if the principal deposition axes are exactly perpendicular to the column direction.

This problem is addressed by arranging for each principal deposition axis to extend perpendicular to a lateral direction that differs by an azimuthal angle of 5–25°, typically 10°, from the lateral direction in which focus openings 40 are of maximum dimension. The two deposition positions remain opposite each other so that their principal deposition axes differ azimuthally (i.e., as viewed vertically) by approximately 180°.

By depositing focus coating 39A in this slightly off-perpendicular manner, the focus coating metal accumulates adequately on one of each opposing pair of the above-mentioned portions of row-direction sidewalls 98R during the deposition from one of the positions and adequately on the other of that pair of sidewall portions during the deposition from the other position. The net result is that coating 39A is continuous along the top of base structure 38A including the portions of row-directions sidewalls 98R extending from the tops of row-direction strips 96R down to the tops of column-direction strips 96C. The value of the azimuthal angle and the depths to which coating 39A extends into focus openings 40 along column-direction sidewalls 98C can readily be chosen to avoid having coating 39A extend down any row-direction sidewall in any opening 40 to contact a column electrode 28.

The opposite-position angled deposition can be performed in a serial manner with a single angled deposition source. That is, the focus coating material can be deposited from one of the positions after which the deposition source is adjusted to the other position, and more of the focus coating material is deposited from the second position. Alternatively, the opposite-position angled deposition can be done with two deposition sources, typically simultaneously, with each of the sources at a different one of the two positions.

An important facet of performing the angled deposition from the two opposite positions chosen in the foregoing manner is that the dimensions of openings such as access openings 102, 112, and 114 can readily be chosen to enable the focus coating material to reach the bottoms of these openings even though the focus coating material only goes partway into focus openings 40. This permits focus coating 39 or 39A to be electrically contacted along its lower surface for receiving the focus coating potential without short circuiting coating 39 or 39A to control electrodes 28 at the bottoms of openings 40.

FIG. 13 illustrates how the present opposite-position deposition technique is applied to the field emitter of FIGS. 8 and 9 to form focus coating 39A. Two focus opening rows and seven focus opening columns (including one dummy focus opening column) are shown in FIG. 13. Items 128 and 130 in FIG. 13 represent the opposite positions from which deposition system 122/124 is employed to perform the angled focus metal deposition. Positions 128 and 130 are located laterally outside active region 90 and peripheral region 92. Position 128 is situated beyond regions 90 and 92 to the right of access openings 102. Position 130 is situated beyond regions 90 and 92 to the left of the first column of focus openings 40.

Position 128 is so located that principal deposition axis 126 for deposition system 122/124 is roughly perpendicular

to the column direction subject to the azimuthal variation described above. Likewise, position **130** is so located that principal deposition axis **126** for system **122/124** is roughly perpendicular to the column direction. Inasmuch as focus control is more critical in the row direction than in the column direction, principal deposition axes **126** for positions **128** and **130** extend roughly perpendicular to the lateral direction that is perpendicular to the lateral direction of most critical focus control. Deposition axes **126** also lie in approximately the same vertical plane.

FIGS. **14a** and **14b** depict how the opposite-position deposition with system **122/124** is performed on the field emitter of FIGS. **8** and **9**. Item **132** in FIGS. **14a** and **14b** generally represents the structure (including electron-emissive elements **24** and row electrodes **12**) below control electrodes **28** and base focusing structure **38A**. In FIG. **14a**, the angled deposition is initiated from position **128**. Atoms of the focus coating metal evaporatively accumulate on top of base focusing structure **38A**, partway into focus openings **40** (and dummy focus openings **40D**) along left-hand sidewalls **98C**, and all the way into access openings **102** along left-hand sidewalls **105C** and partway across the portions of access conductor **106** at the bottom of openings **102**.

The field emitter and deposition system **122/124** are rotated through an azimuthal angle of  $180^\circ$  relative to each other to place system **122/124** at position **130**. This can entail moving the field emitter, moving system **122/124**, or moving both the field emitter and system **122/124**.

From position **130**, atoms of the focus coating metal evaporatively accumulate over the top of base focusing structure **38A**, partway into focus openings **40** (and dummy focus openings **40D**) along right-hand sidewalls **98C**, and all the way into access openings **102** along right-hand sidewalls **105C** and partway across the portions of access conductor **106** at the bottoms of openings **102**. The result is that focus coating **39A** penetrates only partway into each focus opening **40** (or **40D**) but all the way down into access opening **102** along at least both of sidewalls **105C**. Access conductor **106** thus electrically contacts focus coating **39A** along its lower surface within openings **102** without being short circuited to control electrodes **28** in any of focus openings **40**.

The amount that focus coating **39A** penetrates into each focus opening **40** along left-hand sidewall **98C** relative to right-hand sidewall **98C** varies somewhat from opening **40** to opening **40**. With suitable choices for the deposition parameters, this variation is normally sufficiently small that few electrons are underfocused or overfocused and reach unintended light-emissive elements in the light-emitting device situated opposite the field emitter in the final FED. In the example shown in FIG. **14b**, the focus coating metal does not accumulate fully across the parts of access conductor **106** exposed through access openings **102**. A gap **134** is present in focus coating **39A** at the bottom of each opening **102**. Gap **134** can be eliminated by appropriately adjusting the deposition conditions and/or the dimension of openings **102** in the row direction.

Instead of being static, deposition positions **128** and **130** can be translated laterally in a largely fixed laterally direction during the deposition from each of portions **128** and **130**. The translation is typically performed in the column direction. For example, position **128** can be moved from a location near the bottom row of focus openings **40** to a location near the top row of openings **40** (or vice versa). The same applies to position **130**.

With cone half angle  $\alpha$  suitably restricted, moving positions **128** and **130** in the column direction enables the

thickness of focus coating **39A** to be made quite uniform across the top of base focusing structure **38A**. The depths to which coating **39A** extends into focus openings **40** along column-direction sidewalls **98C** can likewise be made quite uniform from one opening **40** to another opening **40** in each column of openings **40**. In addition, translating positions **128** and **130** in the column direction permits positions **128** and **130** to be brought closer to the field emitter. Coating **39A** can thus be deposited on a field emitter of large area without placing the deposition positions far from the field emitter so as to necessitate a very large deposition chamber.

During the opposite-position angled deposition, a shadow mask (not shown) is typically employed at the periphery of focus coating **38A** to prevent the focus coating metal from accumulating on the exposed ends of electrodes **28**, **28D**, and **12** and conductor **106** to short them together. Alternatively, any of the focus coating metal that accumulates on the exposed ends of electrodes **28**, **28D**, and **12** and conductor **106** can be removed according to a suitable masked etch procedure depending on the materials that form electrodes **28**, **28D**, and **12** and conductor **106** on one hand, and the focus coating metal, on the other hand.

A flat-panel CRT display containing an electron-emitting device manufactured according to the invention operates in the following way. The anode in the light-emitting device is maintained at high positive potential relative to control electrodes **28** and emitter electrodes **12**. When a suitable potential is applied between (a) a selected one of control electrodes **28** and (b) a selected one of emitter electrodes **12**, the so-selected gate portion **32** extracts electrons from the selected set of electron-emissive elements **24** and controls the magnitude of the resulting electron current. Desired levels of electron emission typically occur when the applied gate-to-cathode parallel-plate electric field reaches 20 volts/ $\mu\text{m}$  or less at a current density of  $0.1 \text{ mA/cm}^2$  as measured at the light-emissive elements when they are high-voltage phosphors. The extracted electrons pass through the anode layer and selectively strike the phosphor elements, causing them to emit light visible on the exterior surface of the light-emitting device.

Directional terms such as “top”, “bottom”, “upper”, and “lower” have been employed in describing the present invention to establish a frame of reference by which the reader can more easily understand how the various parts of the invention fit together. In actual practice, the components of the present electron-emitting device may be situated at orientations different from that implied by the directional items used here. The same applies to the way in which the fabrication steps are performed in the invention. Inasmuch as directional items are used for convenience to facilitate the description, the invention encompasses implementations in which the orientations differ from those strictly covered by the directional terms employed here.

While the invention has been described with reference to particular embodiments, this description is solely for the purpose of illustration and is not to be construed as limiting the scope of the invention claimed below. For instance, deposition system **122/124** can be rotated around the field emitter (or vice versa) during the deposition of focus coating **39A** as incidence angle  $\theta$  is appropriately adjusted to enable coating **39A** to extend partway down column-direction sidewalls **98C** but not fully down row-direction sidewalls **98R**. Incidence angle  $\theta$  is reduced in value as system **122/124** rotates relative to the field emitter from a position in which principal deposition axis **126** is perpendicular to the column direction to a position in which axis **126** is parallel to the column direction, and vice versa.

Focus openings **40** and access openings **102**, **112**, and **114** can have non-rectangular shapes. The techniques used to deposit coating **39A** can be applied to focus coating **39**. Deposition techniques other than evaporation can be employed to form coating **39** or **39A**.

Each of the sets of electron-emissive elements **24** can consist of only one element **24** rather than multiple elements **24**. Multiple electron-emissive elements can be situated in one opening through dielectric layer **22**. Electron-emissive elements **24** can have shapes other than cones. One example is filaments, while another is randomly shaped particles such as diamond grit.

The principles of the invention can be applied to other types of matrix-addressed flat-panel displays. Candidate flat-panel displays for this purpose include matrix-addressed plasma displays and active-matrix liquid-crystal displays. Various modifications and applications may thus be made by those skilled in the art without departing from the true scope and spirit of the invention as defined in the appended claims.

We claim:

**1.** A system for focusing electrons emitted by an electron-emissive element (a) situated in a dielectric opening in a dielectric layer and (b) exposed through a control opening in an overlying control electrode, the system comprising:

an access electrical conductor overlying the dielectric layer;

a base focusing structure overlying the dielectric layer and penetrated by a focus opening located above the electron-emissive element; and

a focus coating overlying the base focusing structure, the access conductor being electrically coupled to the focus coating along a lower surface of the focus coating.

**2.** A system as in claim **1** wherein the focus coating comprises electrically non-insulating material.

**3.** A system as in claim **2** wherein the focus coating is of lower resistivity than the base focusing structure.

**4.** A system as in claim **1** wherein the focus coating extends only partway down into the focus opening.

**5.** A system as in claim **1** wherein the focus coating is spaced apart from the control electrode.

**6.** A system as in claim **1** wherein the access conductor provides a focus control potential to the focus coating for controlling the focusing of electrons emitted by the electron-emissive element.

**7.** A system as in claim **1** wherein the control electrode and the access conductor consist primarily of the same electrically conductive material.

**8.** A system as in claim **1** wherein the base focusing structure over lies part of the control electrode and part of the access conductor.

**9.** A system as in claim **1** wherein the access conductor is electrically coupled to the focus coating through an access opening that extends through the base focusing structure.

**10.** A system as in claim **9** wherein the access opening is of greater diameter than the focus opening along a straight line running laterally through the centers of the openings at a selected height above the dielectric layer.

**11.** A device comprising:

electron-emitting means comprising a multiplicity of laterally separated sets of electron-emissive elements in an active region of the device;

a dielectric layer having dielectric openings in which the electron-emissive elements are situated;

a plurality of control electrodes overlying the dielectric layer and having control openings through which the electron-emissive elements are exposed; and

a focusing system for focusing electrons emitted by the electron-emissive elements, the focusing system comprising (a) an access electrical conductor overlying the dielectric layer, (b) a base focusing structure overlying the dielectric layer and penetrated by a like multiplicity of focus openings located respectively above the sets of electron-emissive elements, and (c) a focus coating overlying the base focusing structure and extending into each focus opening, the access conductor being electrically coupled to the focus coating along a lower surface of the focus coating outside the active region.

**12.** A device as in claim **11** wherein the focus coating comprises electrically non-insulating material.

**13.** A device as in claim **12** wherein the non-insulating material of the focus coating consists of primarily of at least one of aluminum, chromium, nickel, silver, and gold.

**14.** A device as in claim **11** wherein the access conductor is electrically coupled to the focus coating through an access opening extending through the base focusing structure.

**15.** A device as in claim **14** wherein the active region is generally shaped laterally like a rectangle having a pair of opposing first sides and a pair of second opposing sides that respectively meet the first sides, the access opening being closer to one of the first sides than any of the other three sides and being of greater maximum dimension than each focus opening in the lateral direction generally parallel to either second side.

**16.** A device as in claim **14** wherein the access conductor is electrically coupled to the focus coating along the lower surface of the focus coating through at least one further access opening extending through the base focusing structure outside the active region.

**17.** A device as in claim **16** wherein at least one further structure overlies and contacts the focus coating above at least one location between each pair of access openings.

**18.** A device as in claim **17** wherein each further structure comprises a spacer for separating the focusing system from a light-emitting device.

**19.** A device as in claim **11** further including anode means situated above, and spaced apart from, the electron-emissive elements for collecting electrons emitted by the electron-emissive elements.

**20.** A device as in claim **19** wherein the anode means is part of a light-emitting device having a like multiplicity of laterally separated light-emissive elements situated respectively opposite the sets of electron-emissive elements for emitting light upon being struck by electrons emitted from the electron-emissive elements.

**21.** A method comprising the following steps for manufacturing a system that focuses electrons emitted by an electron-emissive element situated in a dielectric opening in a dielectric layer:

furnishing over the dielectric layer (a) a control electrode having a control opening that exposes the electron-emissive element and (b) an access electrical conductor;

forming a base focusing structure over the dielectric layer such that a focus opening extends through the base focusing structure above the electron-emissive element; and

providing a focus coating over the base focusing structure such that the access conductor is electrically coupled to the focus coating along a lower surface of the focus coating.

**22.** A method as in claim **21** wherein the focus coating comprises electrically non-insulating material.

**23.** A method as in claim **21** wherein the furnishing step comprises:

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forming a control layer over the dielectric layer; and  
 patterning the control layer to form at least part of the  
 control electrode and at least part of the access con-  
 ductor.

24. A method as in claim 21 wherein the providing step  
 comprises physically depositing focus coating material over  
 the base focusing structure at an average incidence angle  
 which, as measured relative to a plane running generally  
 parallel to the dielectric layer, is sufficiently small that the  
 focus coating material accumulates only partway down into  
 the focus opening.

25. A method as in claim 24 wherein the providing step is  
 performed by evaporative deposition.

26. A method as in claim 24 wherein the providing step  
 entails directing the focus coating material toward the base  
 focusing structure from a pair of generally opposite posi-  
 tions.

27. A method as in claim 24 wherein:

the forming step entails furnishing an access opening  
 through the base focusing structure above the access  
 conductor; and

the providing step entails electrically coupling the focus  
 coating to the access conductor through the access  
 opening.

28. A method as in claim 27 wherein:

the providing step entails directing the focus coating  
 material toward the focus and access openings from a  
 pair of generally opposite positions, each having a  
 principal deposition axis, both axes extending roughly  
 perpendicular to a first lateral direction;

the focus opening is of greater dimension in the first  
 direction than in a second lateral direction perpendicu-  
 lar to the first direction; and

the average incidence angle is sufficiently large that the  
 focus coating material accumulates deep enough in the  
 access opening to contact the access conductor.

29. A method as in claim 28 wherein focus control of  
 electrons emitted by the electron-emissive element is more  
 critical in the second direction than in the first direction.

30. A method comprising the steps of:

producing an initial structure in which a multiplicity of  
 laterally separated sets of electron-emissive elements  
 of an active region are situated in dielectric openings of  
 a dielectric layer;

furnishing over the dielectric layer (a) a plurality of  
 control electrodes having control openings that expose  
 the electron-emissive elements and (b) an access elec-  
 trical conductor;

forming a base focusing structure over the dielectric layer  
 such that a like multiplicity of focus openings extend

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through the base focusing structure respectively above  
 the sets of electron-emissive elements; and

providing a focus coating over the base focusing structure  
 such that the access conductor is electrically coupled to  
 the focus coating along a lower surface of the focus  
 coating.

31. A method as in claim 30 wherein the focus coating  
 comprises electrically non-conductive material.

32. A method as in claim 30 wherein:

the forming step entails furnishing an access opening  
 through the base focusing structure above the access  
 conductor; and

the providing step entails electrically coupling the focus  
 coating to the access conductor through the access  
 opening.

33. A method as in claim 32 wherein:

the producing step entails forming at least part of the  
 control openings in an array of columns extending in a  
 first lateral direction and rows extending in a second  
 lateral direction different from the first direction;

the forming step entails forming the access opening to be  
 of greater dimension in the second direction than each  
 control opening; and

the providing step entails providing the focusing coating  
 so as to extend only partway down into each focus  
 opening.

34. A method as in claim 33 wherein the providing step  
 comprises physically depositing focus coating material over  
 the base focusing structure at an average incidence angle  
 which, as measured relative to a plane running generally  
 parallel to the dielectric layer, is (a) sufficiently small that  
 the focus coating material accumulates only partway down  
 into the focus openings and (b) sufficiently large that the  
 focus coating material accumulates deep enough in the  
 access opening to contact the access conductor.

35. A method as in claim 34 wherein the providing step  
 entails directing the focus coating material towards the focus  
 and access openings from a pair of opposite deposition  
 positions located beyond, and on opposite sides of, the  
 columns and access opening in the second direction.

36. A method as in claim 35 wherein each deposition  
 position is characterized by a principal deposition axis, both  
 axes extending largely perpendicular to a further lateral  
 direction that differs by up to 25° from the first direction.

37. A method as in claim 36 wherein both deposition  
 positions are translated in largely a specified lateral direction  
 during the providing step.

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